SUBCOURSE MM0323

EDITION 6

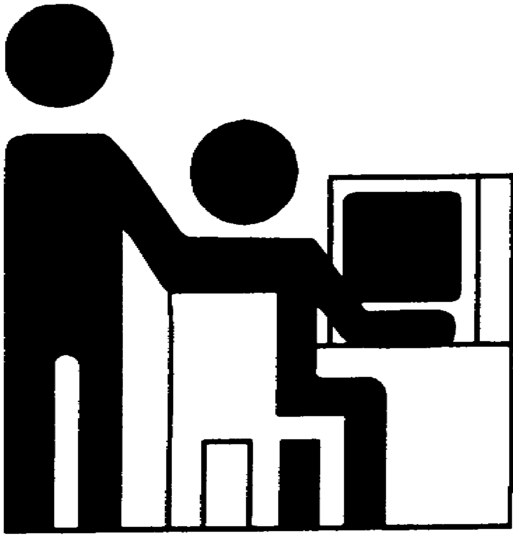
FM RADIO TRANSMITTERS

AIPD

READINESS/ PROFESSIONALISM THRU GROWTH

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM



Notice to Students

Use the Ordnance Training Division website,
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If you have access to a computer with Internet capability and can receive e-mail, we recommend that you use this means to communicate with our subject matter experts. Even if you're not able to receive e-mail, we encourage you to submit content inquiries electronically. Simply include a commercial or DSN phone number and/or address on the form provided. Also, be sure to check the Frequently Asked Questions file at the site before posting your inquiry.

*May 1971

CORRECTIONS TO TM 11-668

Page 9, para 4d(4), lines 30 and 31. Change the formula to:

$$\underline{\Delta F} = \frac{\pi}{6} \times 1{,}000 \times (+1)$$

$$\underline{\Delta F} = +523 \text{ cps (approximately).}$$

Page 20, para 11g(2), line 5. Change "25" to: 15.

Page 29, para 13d, make the following changes:

Line 16. Change "750,000 to: 75,000.

Line 18. Change "750,000" and ".001" to: 75,000 and $.001 \times 10^{-6}$, respectively.

Page 36, para 18c, line 1. Change "shunt-fed" to: series-fed.

Figure 36, caption. Change "Shunt fed" to: Series-fed.

Page 37, para 20, first formula. Change to:

$$X_C = \frac{1}{2\pi f\underline{C}} \text{ ohms.}$$

Page 40, para 22b(3), formula at top of page. Change to:

$$Z_{ab} = \frac{1}{g_m} \times \left(\frac{Z_a + Z_b}{Z_b}\right)$$

$$Z_{ab} = \frac{1}{g_m} \times \left(1 + \frac{Z_a}{Z_b}\right) \qquad g_m = \text{mhos}$$

$$Z_{ab} = \frac{1}{g_m} + \frac{Z_a}{g_m Z_b}$$

Page 94, para 43d(3). Delete line 7, and substitute: less; therefore, a positive voltage.

Page 118, para 59a, lines 17-25. Change to: The over-all output is the quadrature sum of the signal and the noise voltages, multiplied by the stage amplification, or

$$\sqrt{10^2 + 4.4^2} \times 10 = \underline{10.9} \times 10 = 109 \text{ microvolts.}$$

*This edition replaces correction sheet dated April 1969.

Since the second stage of amplification was assumed to be identical with the first, it add 3.2 microvolts of noise to the applied signal of 109 microvolts. The output of the second stage is

$$\sqrt{109^2 + 3.2^2} \times 10 = \underline{109} \times 10 = \underline{1{,}090 \text{ microvolts}}.$$

Page 151, figure 134 A and B. In the label on the vertical side of each graph, change "RESPONSE" to: AMPLITUDE.

PLEASE NOTE

Proponency for this subcourse has changed from Signal (SS) to Missile & Munitions'(MM).

SIGNAL SUBCOURSE 323, FM RADIO TRANSMITTERS

INTRODUCTION

In a field army, a sufficient number of radio sets are available to provide radio communications for all commanders. Most of these radio sets use a type of modulation that is called frequency modulation (FM). These FM radio sets are used to pass various types of communication traffic and also appear in various sizes and shapes. For example: these sets vary from the relatively simple squad type to the highly sophisticated type used in satellite communication terminals. Even though these sets transmit FM signals, there are different methods used to develop these modulated signals.

This subcourse is written to make you aware of different frequency-modulating techniques and to acquaint you with various types of circuits used in FM transmitters.

This subcourse consists of four lessons as follows:

Lesson 1. Principles of FM

Lesson 2. Methods of Producing FM

Lesson 3. FM Transmitter Circuits

Lesson 4. FM Transmitters

Credit Hours: 10

You are urged to finish this subcourse without delay; however, there is no specific limitation on the time you may spend on any lesson or on the examination.

Texts and materials furnished:

Subcourse Booklet

TM 11-668, F-M Transmitters and Receivers, September 1952

REVIEWED AND REPRINTED WITH MINOR REVISIONS AUGUST 1976

Note to student:

Since TM 11-668 was published, the unit of frequency has been changed from cycles per second to hertz. The following equivalents will help you relate the two units.

1 cycle per second (cps) = 1 hertz (Hz)

1 kilocycle per second (kcs) = 1 kilohertz (kHz)
(sometimes kc)

1 megacycle per second (mcs) = 1 megahertz (MHz)
(sometimes mc)

LESSON 1

PRINCIPLES OF FM

SCOPE ....Principles of amplitude modulation (AM), phase modulation (PM), and frequency modulation (FM); effects of the modulating signal's amplitude and frequency on the carrier wave; bandwidth occupied by an FM signal.

CREDIT HOURS 2

TEXT ASSIGNMENT ....TM 11-668, para 1-15; Attached Memorandum, para 1-1

MATERIALS REQUIRED ....None

SUGGESTIONS ....None

LESSON OBJECTIVES

When you have completed this lesson, you will be able to:

1. Compute the needed carrier amplitude and frequency for an FM transmitter when given the limiting conditions.

2. Determine the modulation index and the carrier deviation for an FM transmitter.

3. Determine the changes in signal bandwidth when the modulation index is changed.

4. Use the time-constant formulas to determine circuit response and the component values that are needed for a particular response.

ATTACHED MEMORANDUM

1-1. DEFINITIONS

The following definitions will be used in this lesson.

a. Frequency Deviation. The amount by which a frequency-modulated wave either increases or decreases from the center frequency.

b. Frequency Swing. The peak difference between the maximum and minimum values of instantaneous frequency. Normally considered as twice the frequency deviation.

LESSON EXERCISES

In each of the following exercises, select the ONE answer that BEST completes the statement or answers the question. Indicate your solution by circling the letter opposite the correct answers in the subcourse booklet.

1. The waveform shown in figure 1-1 represents a portion of a carrier wave being radiated from a radio transmitter. The frequency and peak voltage outputs of this transmitter, respectively, are

a. 80 kHz and 5 volts.

b. 80 kHz and 10 volts.

c. 160 kHz and 5 volts.

d. 160 kHz and 10 volts.

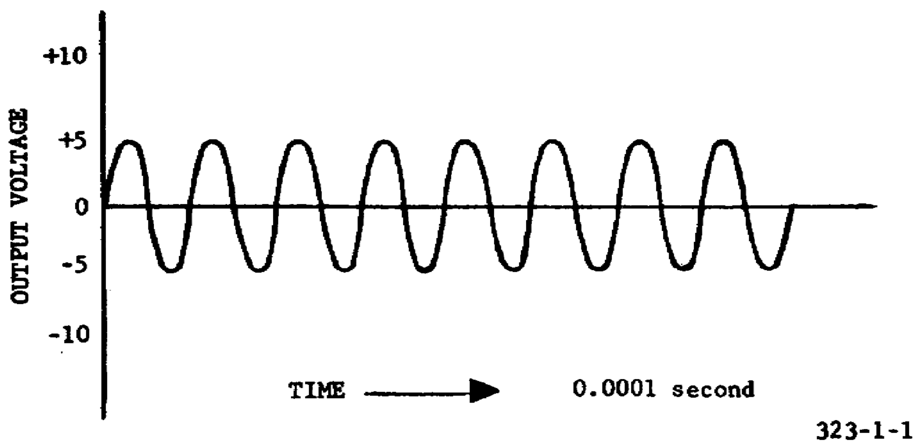

Figure 1-1. Unmodulated carrier wave.

2. Energy can be transmitted over great distances via a radio-frequency carrier wave. Intelligence can be "carried" by this wave if any one of its three characteristics is varied. These characteristics are

a. frequency, phase, and amplitude.

b. starting point, phase, and frequency.

c. amplitude, frequency, and starting point.

d. phase, amplitude, and signal-to-noise ratio.

3. To prevent distortion of the output signal, the operator of an AM radio must keep modulation from going over 100 percent. At the same time, modulation must be as near 100 percent as possible to obtain the maximum power output. Since the modulating signal may reach a peak amplitude of 30 volts, the carrier must have a peak amplitude of at least

a. 15 volts.

b. 30 volts.

c. 45 volts.

d. 60 volts.

4. A commercial AM radio station is transmitting a carrier frequency of 1,120 kHz. The frequency of the modulating signals ranges from 500 Hz to 5 kHz. The radio-frequency (RF) stages of the receiver being used to receive these signals must have a minimum bandwidth of approximately

a. 5 kHz.

b. 10 kHz.

c. 560 kHz.

d. 1,125 kHz.

5. Assume that a phase modulator is producing a 100-kHz carrier. The phase deviation limit is 30° when the carrier is modulated by a 1.2-kHz signal. The minimum and maximum frequency values of the modulated carrier are approximately

a. zero and 628 Hz.

b. 99,372 Hz and 100,628 Hz.

c. 99,686 Hz and 100,314 Hz.

d. 100,000 Hz and 100,628 Hz.

6. Assume that two identical sine-wave sources are used to modulate two transmitters--one is FM and the other is phase modulated (PM). The relationship between the frequency shifts in the two waves is such that the FM wave is at

a. maximum frequency when the PM wave is at its carrier frequency.

b. minimum frequency when the PM wave is at its maximum frequency.

c. minimum frequency when the PM wave is at its minimum frequency.

d. carrier frequency when the PM wave is at its carrier frequency.

7. Sketch C in figure 17 of TM 11-668 is the block diagram of a PM transmitter. The section that is relied upon to produce the maximum amount of frequency deviation is the

a. power amplifier.

b. crystal oscillator.

c. frequency multipliers.

d. audio-correction network.

8. Most military FM transmitters are restricted to maximum frequency deviation of 40 kHz.. If the maximum audio signal is 5 kHz, the modulation index is

a. 1/8.

b. 1/4.

c. 2.

d. 8.

9. Assume an FM station with a maximum carrier deviation of 40 kHz. If the modulation index (MI) is to be 5, the maximum audio frequency that can cause the deviation is

a. 4 kHz.

b. 8 kHz.

c. 15 kHz.

d. 20 kHz.

10. Assume that one of your unit's FM transmitters has a 60-MHz carrier frequency arid its frequency deviation must not exceed 40 kHz. If the percentage of modulation is 80 percent, the deviation is

a. 20 kHz.

b. 32 kHz.

c. 40 kHz.

d. 64 kHz.

11. Assume that a military FM transmitter is operating on a channel that extends from 92.1 MHz to 92.2 MHz. Since military communication standards require a 10-kHz guard hand on each end of the channel, the maximum permissible frequency deviation is

a. 20 kHz.

b. 40 kHz.

c. 60 kHz.

d. 80 kHz.

12. An FM transmitter being modulated by a 10-kHz audio tone signal has an MI of 5. If the MI is increased to 15 by increasing the amplitude of the modulating signal, the effective bandwidth will be increased from

a. 40 kHz to 70 kHz.

b. 40 kHz to 160 kHz.

c. 160 kHz to 380 kHz.

d. 160 kHz to 480 kHz.

13. Assume that a commercial broadcast FM transmitter has a carrier frequency (fc) of 97.400 MHz and is modulated with a 3-kHz signal. A spectrum analysis indicates that the highest significant frequency (fs) in the output is 97.475 MHz. The MI of this transmitter is

a. 0.5.

b. 7.5.

c. 20.0.

d. 25.0

14. An FM transmitter has a deviation of 20 kHz, and a modulation index of 20 when modulated by a 1-kHz rectangular wave. If the transmitter is to have the same bandwidth when modulated by a 1-kHz triangular wave, it must have a deviation of 3 kHz and a modulation index of

a. 0.3.
c. 3.0.

b. 1.5.
d. 20.

15. When a given FM transmitter is modulated by a 1.5-kHz sine wave, the effective bandwidth is 24 kHz and the frequency deviation is 7.5 kHz. If the transmitter is modulated by a rectangular pulse having a pulse repetition rate of 1.5 kHz and the frequency deviation is held at 7.5 kHz, the modulation index remains at 5 and the effective bandwidth will be

a. 24 kHz.
c. 60 kHz.

b. 48 kHz.
d. 75 kHz.

16. Assume that the preemphasis network in A of figure 1-2 is altered to have a time constant of 75 microseconds. The deemphasis circuit to be used in the receiver is shown in B of figure 1-2. The value of capacitance used in this circuit should be

a. 0.0015 microfarad.

b. 0.0020 microfarad.

c. 0.0100 microfarad.

d. 0.0375 microfarad.

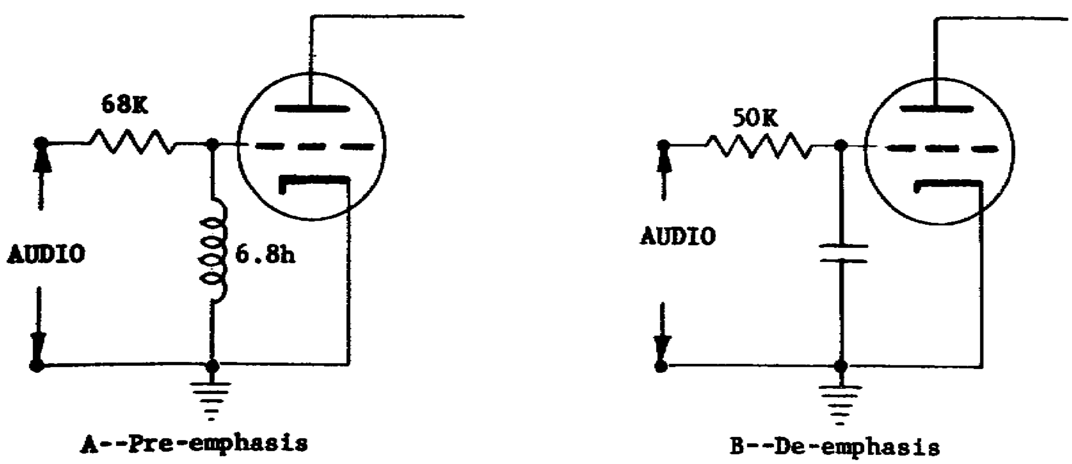

Figure 1-2. Preemphasis and deemphasis circuits.

17. Assume that when a 3-kHz signal is applied to the circuit shown in A, figure 32 of TM 11-668, the signal between the grid and cathode is 4 volts. If the frequency of the input signal is increased to 15 kHz, the signal voltage between the grid and cathode should be

a. 4 volts. c. 16 volts.

b. 8 volts. d. 48 volts.

18. The time constant of a preemphasis network is chosen to provide selective amplification of certain frequency bands. The time constant of the preemphasis network shown in figure 1-2 is approximately

a. 45 microseconds. c. 100 microseconds.

b. 75 microseconds. d. 150 microseconds.

19. The characteristic of FM that makes it more useful in military applications than AM is its

a. interference-free communication.

b. efficiency at high frequencies.

c. high-fidelity reception.

d. wide acceptance band.

20. Assume that the amplitude of a desired signal at the input of an FM receiver is 2 microvolts, and that other signals are present with frequencies lying within the receiver acceptance band. If the receiver output is to be free of interference noise, the amplitude of the undesired signals must have a maximum limit of approximately

a. 0.002 microvolt.

b. 0.02 microvolt.

c. 1 microvolt.

d. 4 microvolts.

CHECK YOUR ANSWERS WITH LESSON 1 SOLUTION SHEET PAGE 47, 48 and 49.

LESSON 2

METHODS OF PRODUCING FM

SCOPE....................................Study of the methods used to produce direct and indirect FM; circuits used as modulators in direct and indirect FM systems.

CREDIT HOURS.............................2

TEXT ASSIGNMENT..........................TM 11-668, para 18-36;
Attached Memorandum, para 2-1 thru 2-4

MATERIALS REQUIRED.......................None

SUGGESTIONS..............................Read the assignment in TM 11-668 before you read the attached memorandum.

LESSON OBJECTIVES

When you have completed this lesson, you will be able to:

1. Determine the frequency deviation produced by modulated oscillators.

2. Determine the amplification factor, load impedance, and injected reactances for reactance tube modulator stages.

3. Identify and know the operation of the various modulator circuits.

4. Use the block and schematic diagrams of an FM transmitter to determine whether direct or indirect FM is being used.

ATTACHED MEMORANDUM

2-1. ESTABLISHING FREQUENCY MODULATION

<u>a</u>. <u>General</u>. The input and output waveforms of an FM oscillator are shown in figure 2-1. In an FM transmitter, the modulation is accomplished at the oscillator stage. A transistor oscillator can be modulated in the same manner as an electron-tube oscillator or by varying the oscillator gain at the modulating rate. The same amplitude-modulated oscillator used in an AM transmitter can be used in an FM transmitter. The unwanted amplitude changes can be removed by a limiter stage before the carrier signal is increased in frequency and magnitude.

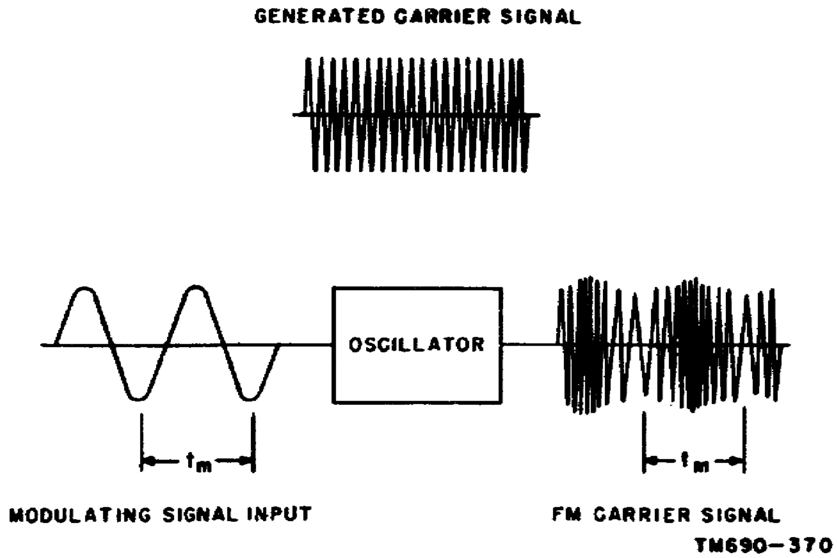

Figure 2-1. FM oscillator, block diagram.

b. FM Oscillator.

(1) A typical FM oscillator stage is shown in figure 2-2. In this application, the modulation is established by reactance modulation. The modulating signal, coupled through transformer T2, varies the emitter-base bias of reactance modulator Q2. Since the bias is increasing and decreasing at the modulation rate, the collector voltage also increases and decreases at the modulating rate. As the collector voltage increases, output capacitance C_{CE} decreases, and as the collector voltage decreases, output capacitance C_{CE} increases. When output capacitance C_{CE} increases, the resonant frequency of the oscillator Q1 tank circuit (capacitor C1 and winding 1-3 of transformer T1) increases. When output capacitance C_{CE} increases, the resonant frequency of the oscillator tank circuit decreases. The resonant frequency of the oscillator tank circuit is therefore increasing and decreasing at the modulating rate, as does the frequency of the signal generated by the oscillator. The output of the oscillator is an FM carrier signal.

(2) Transistor Q1 provides the oscillator signal. Capacitor C1 and winding 1-3 of transformer T1 form a parallel resonant circuit for the oscillator frequency. Winding 4-5 of transformer T1 provides the required feedback, and winding 6-7 couples the oscillator signal to the following stage. Transformer T2 couples the modulating signal to reactance modulator Q2. The reactance of output capacitance C_{CE} across winding 2-3 of transformer T1 varies the resonant frequency of the oscillator tank circuit (capacitor C1 and winding 1-3 of transformer T1).

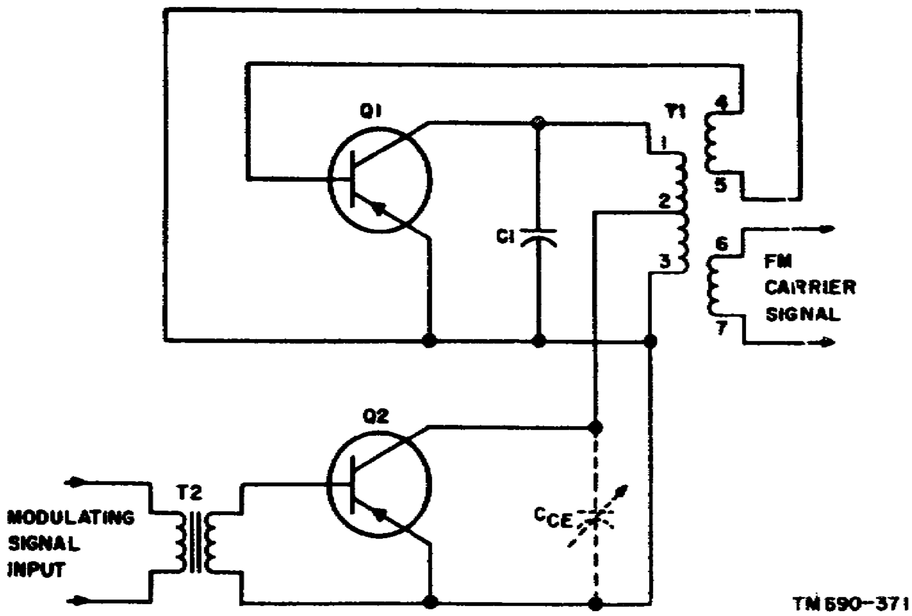

Figure 2-2. Oscillator circuit, frequency-modulated by a reactance modulator.

2-2. USE OF FM OSCILLATOR

An FM oscillator establishes the fundamental frequency-modulated carrier signal necessary for transmission. The requirements for producing an FM carrier using transistors are the same as those for electron tubes. A block diagram of a typical FM transmitter with waveforms is shown in figure 2-3. The audio signal (modulating signal) is applied to the oscillator stage. The output of the oscillator stage is an AM and FM carrier signal. The limiter stage removes the AM and its output is an FM carrier signal with constant amplitude. The multiplier stage increases the frequency to the desired transmitting frequency. The power amplifier stage increases the magnitude of the FM carrier signal sufficiently to drive the antenna.

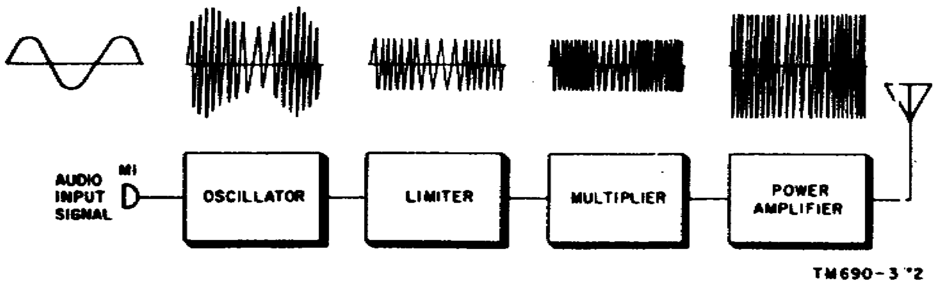

Figure 2-3. FM transmitter, block diagram showing waveforms.

2-3. MILLER-EFFECT MODULATOR

a. Circuit Description. The modulator shown in figure 2-4 employs the Miller effect to vary the equivalent capacitance across a tuned circuit. In the circuit diagram, a complete modulator-oscillator is shown. Transistor Q2 operates as a Colpitts oscillator. Feedback is from the emitter through a capacitively tapped tuned circuit to the base. The operating point is determined by the conventional base voltage divider R6, R7, and emitter bias resistor R8.

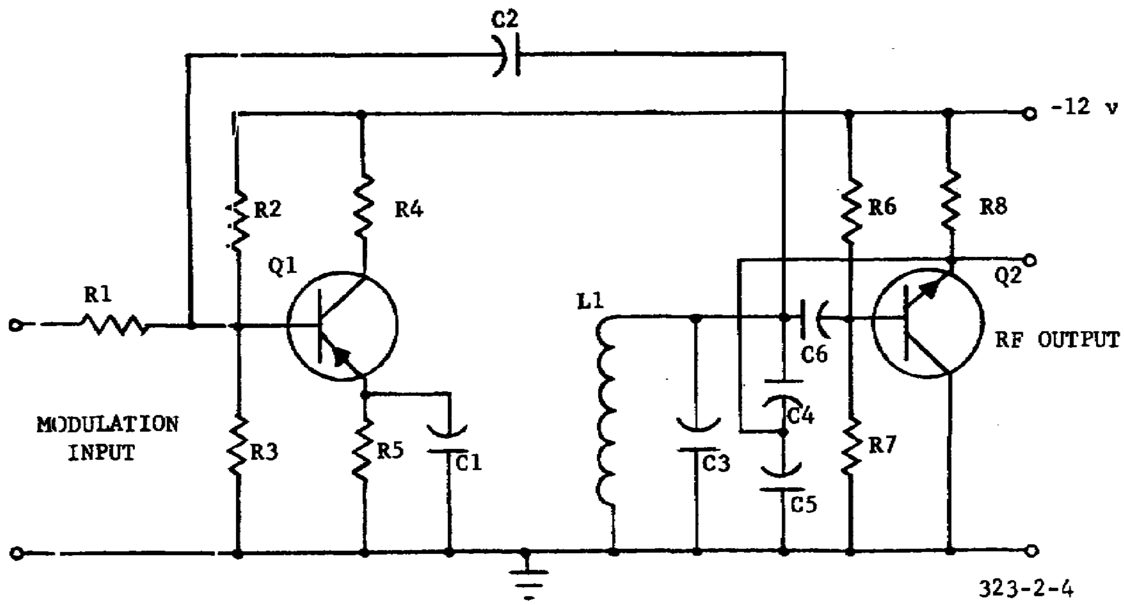

Figure 2-4. Miller-effect modulator.

b. Operation. The modulator, Q1 has an input capacitance at the base that is approximately equal to the emitter junction capacitance plus the voltage gain multiplied by the collector capacitance. If the gain is varied by modulating the operating point of the transistor, the input capacitance of Q1 will change (Miller effect) and frequency modulation occurs.

2-4. REACTANCE MODULATOR ASSEMBLY

a. Speech Amplifier. The transmitter speech amplifier shown in figure 2-5 amplifies the audio-frequency signals from an external microphone or a remote source. The amplified output from this emitter follower is coupled through coupling capacitor C1 and isolating resistor R3 to the oscillator circuit.

b. Oscillator. The output from the speech amplifier modulates the modified Colpitts oscillator to provide an FM output.

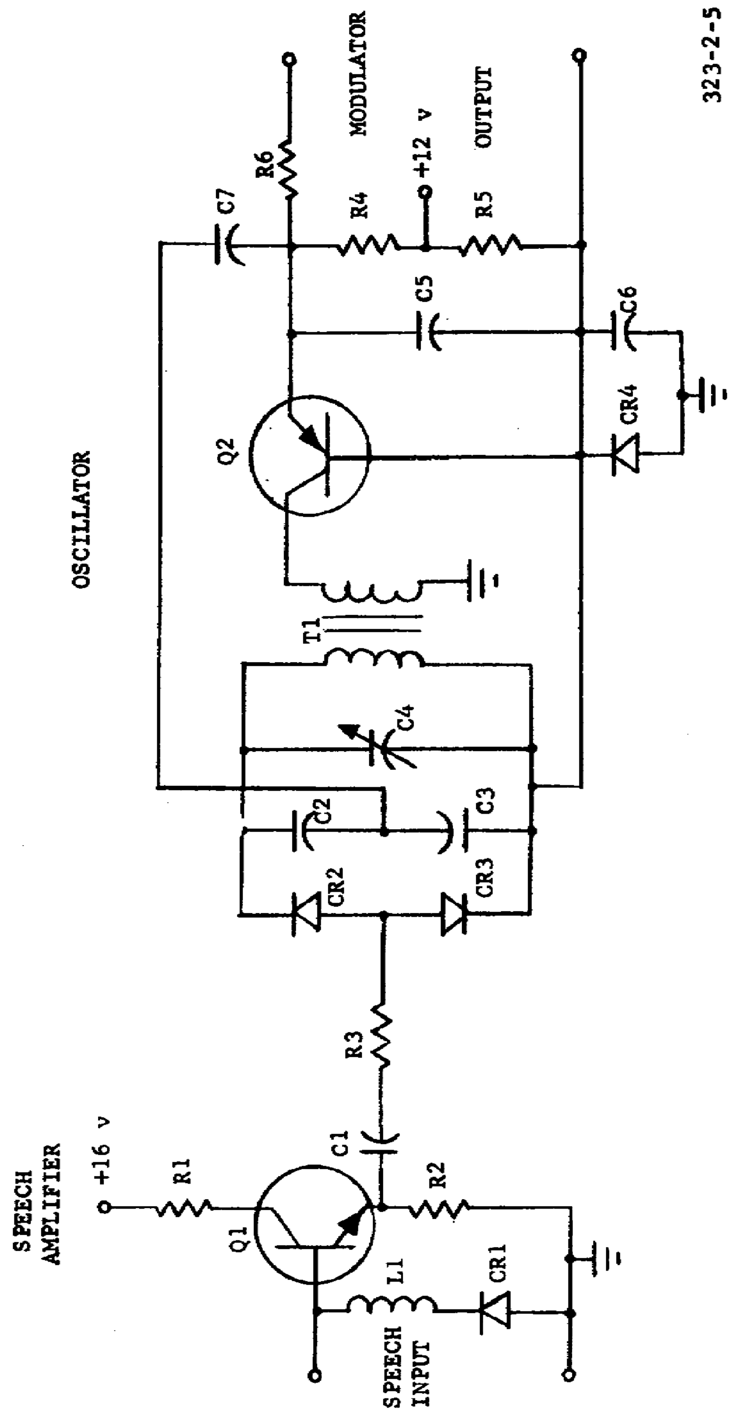

Figure 2-5. Modulator assembly.

(1) The oscillator's tuned circuit consists of transformer T1, trimmer capacitor C4, capacitors C2 and C3, and varactor diodes CR2 and CR3. Capacitors C2 and C3 also serve to match the output impedance of the oscillator to the input impedance of the following stage. Capacitor C7 couples the output back to the emitter to sustain oscillations. Emitter-to-base bias is developed across resistor R4 and C5. Base bias is developed at the junction of R5, zener diode CR4, and C6.

(2) The audio frequency output from the speech amplifier is coupled to the junction of varactor diodes CR2 and CR3. This varying voltage causes the effective capacitance of the diodes to change. These changes in effective capacitance, in accordance with the audio frequency, cause the oscillator frequency to change. Therefore, the output of the oscillator is an FM signal that varies in accordance with the audio frequency from the speech amplifier.

c. Reactance Modulation. The speech amplifier performs the same basis function as the reactance-tube modulator described in TM 11-668. The amplifier changes the incoming amplitude variations of the audio frequency signal into a varying reactance, which is injected into the oscillator's tank circuit. These variations cause changes in the capacitance of CR2 and CR3, which result in capacitive reactance changes in the oscillator's tank circuit.

LESSON EXERCISES

In each of the following exercises, select the ONE answer that BEST completes the statement or answers the question. Indicate your solution by circling the letter opposite the correct answers in the subcourse booklet.

1. Assume that the circuit shown in figure 37 of TM 11-668 is used to produce an FM signal. When the. value of inductance L is 0.9 microhenry (uh) and capacitance C is 0.002 microfarad, the center frequency is 3.75 MHz. If the microphone diaphragm is moved s, that the capacitance is raised to 0.004 microfarad, the frequency deviation will be approximately

a. 0.10 MHz.

b. 1.10 MHz.

c. 2.65 MHz.

d. 3.70 MHz.

2. The Hartley oscillator circuit shown in figure 36 of TM 11-668 is of the type used as the master oscillator in a portable FM transmitter. When the value of coil L is 30 microhenries and the value of capacitor C is 94 picofarads (94×10^{-12} farads), the operating frequency is 3 MHz. If the value of inductance is changed to decrease the frequency to 2.5 MHz, the increase in inductive reactance is approximately

a. 50 ohms.

b. 110 ohms.

c. 300 ohms.

d. 560 ohms.

SITUATION

The reactance-tube modulator used in a short-range, military FM radio transmitter is shown in figure 2-6. Coil L and capacitor C make up the frequency-determining circuit of the Hartley oscillator that provides a center frequency of 22.6 MHz. The characteristics of the modulator tube are as follows:

transconductance (gm) = 5,000 micromhos.

ac plate resistance (r_p) = 0.7 megohm.

Exercises 3 thru 5 are based on this situation.

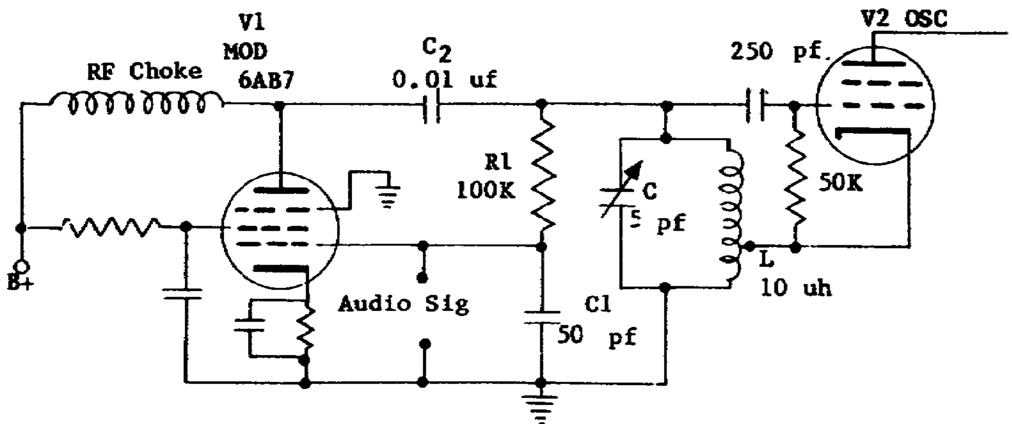

Figure 2-6. Reactance-tube modulator.

3. The electron-tube characteristics described in paragraph 21 of TM 11-668 are computed under static conditions, that is, without a load resistance. The amplification factor of the electron tube used in the modulator circuit is approximately

a. 2,500. c. 5,000.

b. 3,500. d. 7,100.

4. At the center frequency of the oscillator, the impedance across the plate load consisting of R1 and C1 is

a. less than 1OOK. c. between 125K and 150K.

b. between 100K and 125K. d. greater than 200K.

5. When an audio signal is applied, the reactance-tube modulator adds an inductance to the oscillator tank circuit. The amount of inductance injected by the plate load is

a. 100 millihenry (mh).
b. 50 mh.
c. 10 mh.
d. 1 mh.

6. In the reactance-tube modulator represented by figure 38 of TM 11-668, Z_a is always made large in respect to Z_b because it controls the phase of the current through the plate load. The frequency deviation of a transmitter utilizing this circuit is controlled primarily by the value of

a. impedance in Z_a
b. impedance in Z_b.
c. tank circuit components L and C.
d. transconductance of the reactance tube.

7. Assume that in figure 38 of TM 11-668 the box labeled Z_a represents a 50-picofarad (pf) capacitor, and the box labeled Z_b represents a 1,000-ohm resistor. If the modulator tube has a transconductance of 7,000 micromhos, the reactance component injected into the oscillator tank circuit is equivalent to a

a. 350-uh inductor.
b. 7-uh inductor.
c. 7-pf capacitor.
d. 350-pf capacitor.

8. The circuit shown in figure 43 of TM 11-668 is used to modulate a 40-MHz oscillator. Assume that, with no audio signal applied, this circuit injects an inductance of 7.6 uh into the oscillatory circuit. If L_L = 0.4 mh and R_L = 15K, a tube must be selected that has a transconductance of approximately

a. 1,500 micromhos.
b. 3,500 micromhos.
c. 7,000 micromhos.
d. 9,000 micromhos.

9. Assume that each of the four RC sections of the oscillator in C of figure 48, TM 11-668, has a phase shift of 45° at 4 kHz. When the resistance of the variable resistance leg (modulator tube) is increased, the phase shift for that section is reduced to 30° and the output frequency is lowered. To retain the 180° total phase shift, the phase shift in each of the other RC circuits is now

a. 30°.
b. 45°.
c. 50°.
d. 60°.

10. In producing indirect frequency modulation, the equivalent frequency deviation of the modulated wave is proportional to the modulating frequency. This undesirable effect is eliminated by using a

a. circuit with an output that is inversely proportional to the frequency.

b. phase-shift modulator with a constant impedance network.

c. circuit that functions as a variable resistance.

d. quartz-crystal oscillator with a stable frequency.

11. Which phase modulator would be used in an FM transmitter to provide the greatest initial phase deviation?

a. Link-phase modulator

b. Sonar-phase modulator

c. Reactance-tube phase modulator

d. Nonlinear-coil modulator

12. Assume that the carrier shown in A of figure 56 (TM 11-668) is being modulated by the audio wave shown in B. To obtain a phase-modulated waveform like that shown in F, the output from a nonlinear-coil modulator must be applied to a

a. tuned circuit, RF oscillator, and rectifier.

b. limiter, tuned circuit, and RF oscillator.

c. RF oscillator, rectifier, and limiter.

d. rectifier, limiter, and tuned circuit.

13. Assume that a carrier with a peak amplitude of 10 volts is being phase-modulated by a signal with a peak amplitude of 6 volts. Figure 58 of TM 11-668 indicates the presence of an amplitude component that must be removed by limiting. The peak amplitude of this component is

a. less than 2 volts.

b. between 2 volts and 6 volts.

c. between 6 volts and 10 volts.

d. greater than 10 volts.

14. Frequency modulation of the circuit shown in figure 2-2 is accomplished by reactance modulation. The reactive component that is varied to produce the FM is

a. C_{CE} of Q1.
c. T1.

b. C_{CE} of Q2.
d. C1.

15. Modulation of the Colpitts oscillator shown in figure 2-5 is attained by varying the reactance of components labeled

a. CR2 and CR3.
c. C7 and C4.

b. CR2 and T1.
d. C2 and C3.

16. Some FM transmitters incorporate a limiter stage prior to the multiplier stages. The purpose of this limiter stage is to remove the

a. phase variations from the signal.

b. sideband frequencies from the signal.

c. frequency variations from the signal.

d. amplitude variations from the signal.

17. In the modulator assembly shown in figure 2-5, capacitors C2 and C3 serve a dual purpose--they operate as part of the oscillator tuned circuit and they also

a. develop the oscillator emitter-to-base bias.

b. couple the regenerative feedback to the emitter circuit.

c. emphasize the high frequencies in the modulating signal.

d. match the oscillator impedance to that of the following stage.

18. In the Miller-effect modulator shown in figure 2-4, frequency modulation of the oscillator is produced by injecting the reactive changes from Q1 into the tuned circuit of Q2. The frequency deviation that is produced in Q2 is controlled by the

a. reactance of L1.

b. capacitance of C2.

c. input capacitance of Q1.

d. feedback voltage to the tapped capacitors.

19. All oscillators require that a portion of the output be fed back to the input to sustain oscillations. The component used to provide this feedback in the FM oscillator shown in figure 2-5 is labeled

a. C4.
c. T1.

b. C7.
d. CR4.

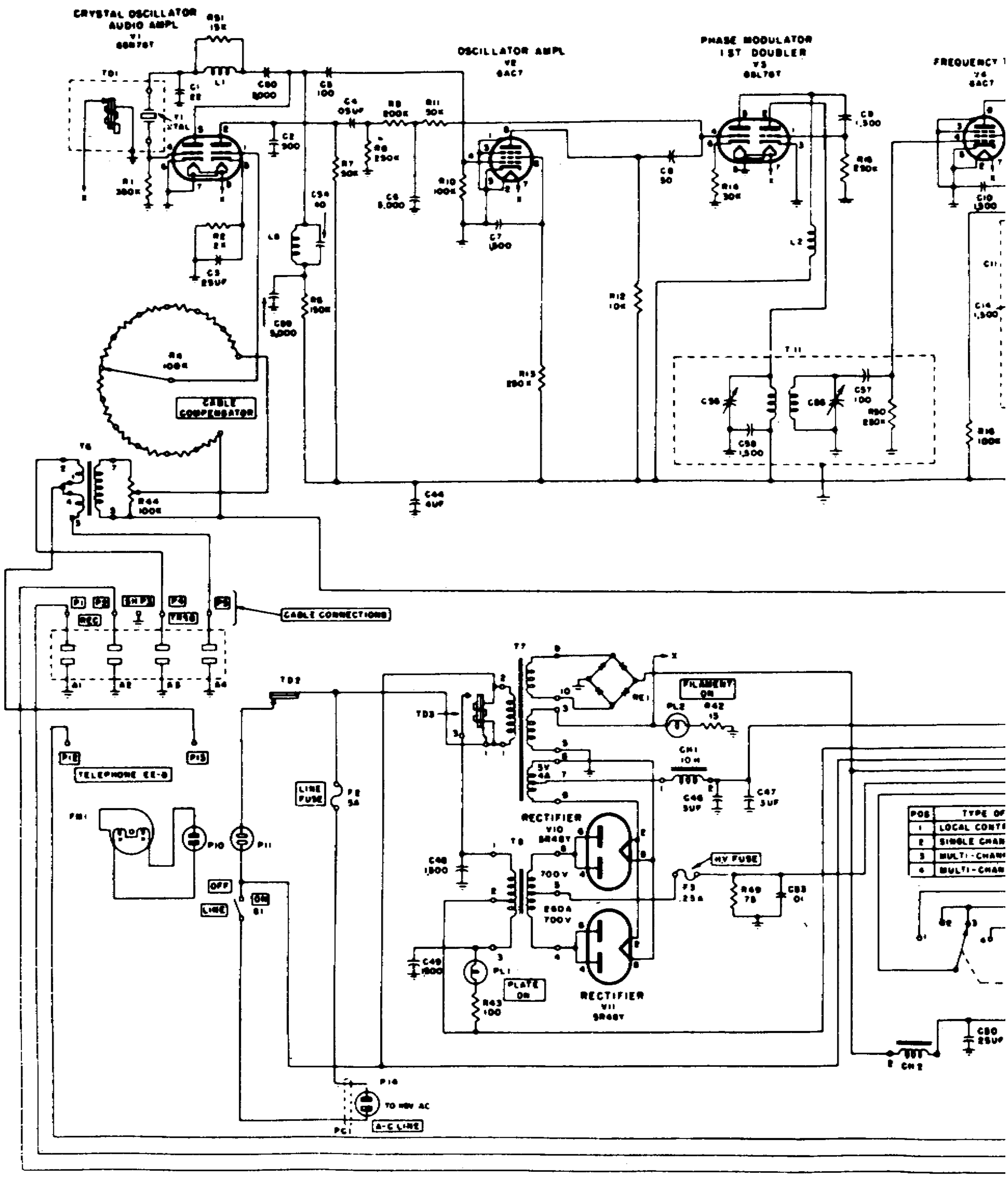

Figure 2-7. FM transmitter.

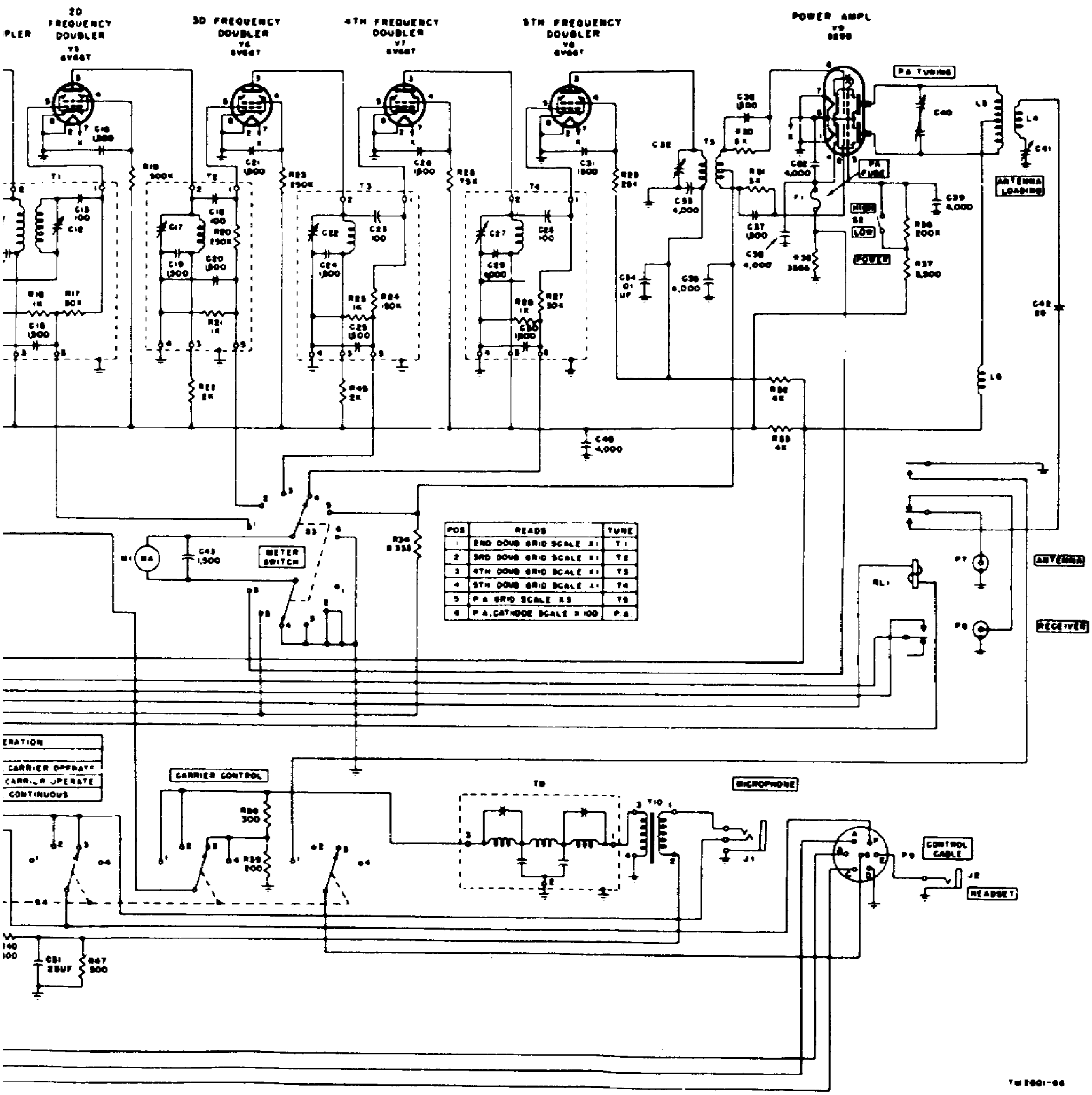

Figure 2-7. FM transmitter. (cont)

20. Assume that the schematic diagram of the FM transmitter shown in figure 2-7 is being used in a classroom to illustrate different types of electron-tube circuits. The type of modulator employed in this transmitter is a

a. reactance-tube modulator.

b. sonar-phase modulator.

c. link-phase modulator.

d. balanced modulator.

CHECK YOUR ANSWERS WITH LESSON 2 SOLUTION SHEET PAGE 49 , 50, 51 and 52.

LESSON 3

FM TRANSMITTER CIRCUITS

SCOPE....................................Principles of operation of frequency multipliers and power amplifiers; impedance matching problems in FM transmitters.

CREDIT HOURS.............................2

TEXT ASSIGNMENT..........................TM 11-668, para 39-41;
Attached Memorandum, para 3-1 thru 3-7

MATERIALS REQUIRED.......................None

SUGGESTIONS..............................Read the assignment in TM 11-668 before you read the attached memorandum.

LESSON OBJECTIVES

When you have completed this lesson, you will be able to:

1. Determine the amount of multiplication and the number of multiplier stages needed to produce a given frequency.

2. Explain that frequency multipliers are basically RF amplifiers and how they are tuned to the frequency of the desired harmonic.

3. Describe the input, output, and operating characteristics of the different power amplifier circuits.

4. Calculate the impedances needed for maximum power transfer between stages in the FM transmitter.

ATTACHED MEMORANDUM

3-1. MULTIPLIER THEORY

a. Design Considerations. The frequency multiplier normally consists of a class C amplifier with its output tuned to a multiple of the input frequency. The considerations involved in the design of transistor frequency multipliers are much the same as those in electron-tube class C amplifiers, with one exception--the harmonic content of the collector-current pulse is very sensitive to the phase angle of the collector current flow. The correct collector phase angle must be chosen with respect to the input for the desired frequency ratio.

b. Efficiency. The optimum phase angle, expressed in degrees, is approximately 180 divided by the order of the harmonic; thus, when doubling, 90° should be used. The collector circuit efficiency decreases as the ratios increase and are given approximately 100 divided by the order of the harmonic.

c. Effects on Gain. Unfortunately, the current gain of the transistor used in a multiplier circuit decreases as the frequency and current increase. This causes difficulty in obtaining the desired conduction angles at the higher frequencies. Hence, the collector-current pulses may be broadened because of the random times taken for the holes to diffuse through the base region, and the tops of the pulses may be rounded because of the decrease of the current amplification factor (a_{fe}) with emitter current. These effects are difficult to evaluate; therefore, as a practical matter, an experimental approach is usually made to obtain the best operating conditions. Assume that a transistor is driven, at the base, and the self-bias for the transistor is controlled by a variable time-constant circuit. The phase angle of the collector current can be altered by changing the amplitude of the drive and by changing the time constant. The load impedance can be varied in the collector circuit to effect the optimum transfer of power. If a chain of frequency multipliers is to be used, each stage must be capable of driving the following one. The use of push-pull stages is advantageous with odd-frequency ratios, while the push-push connection is helpful with even ratios. The use of two transistors per stage effectively doubles the power output.

3-2. MULTIPLIER CIRCUIT CHARACTERISTICS

a. Operating Potentials. The frequency multiplier, shown in figure 3-1, is a simple, low-level class C amplifier employing the type of dc stabilization that is normally used with class A stages. The zero signal operating point, 15 volts at 3 milliamperes (ma), is chosen well below the maximum dissipation of the transistor. The collector voltage is made as high as possible without exceeding the breakdown voltage of the transistor on negative collector swings. The transistor used as a multiplier should have good high-frequency response and relatively high collector voltage and dissipation ratings.

b. Circuit Testing. The capabilities of the multiplier circuit are determined by applying a constant input frequency of 1 MHz from a signal generator, which is adjusted to produce the optimum drive amplitude for the particular frequency ratio under test. The load impedance is adjusted by the substitution of various small, high-frequency-type carbon resistors until the maximum power output is obtained. The tuned circuit LC is kept at a medium value of impedance ($X_L = X_C = 300$ ohms) so that a loaded Q of 30 or more can be obtained at the higher harmonics. In the chart below F_{OUT} is the output frequency, R_L is the

F_{OUT} (MHz)	R_L (ohms)	P_{OUT} (mw)	N (%)	Vi (volts)
1	3.3K	37	82	0.4
2	6.8K	21	47	1.0
3	10K	14	31	1.1
4	10K	10	22	1.2
5	10K	6.4	14	1.3
6	10K	3.6	8	1.4
7	10K	2.5	5.5	2.0

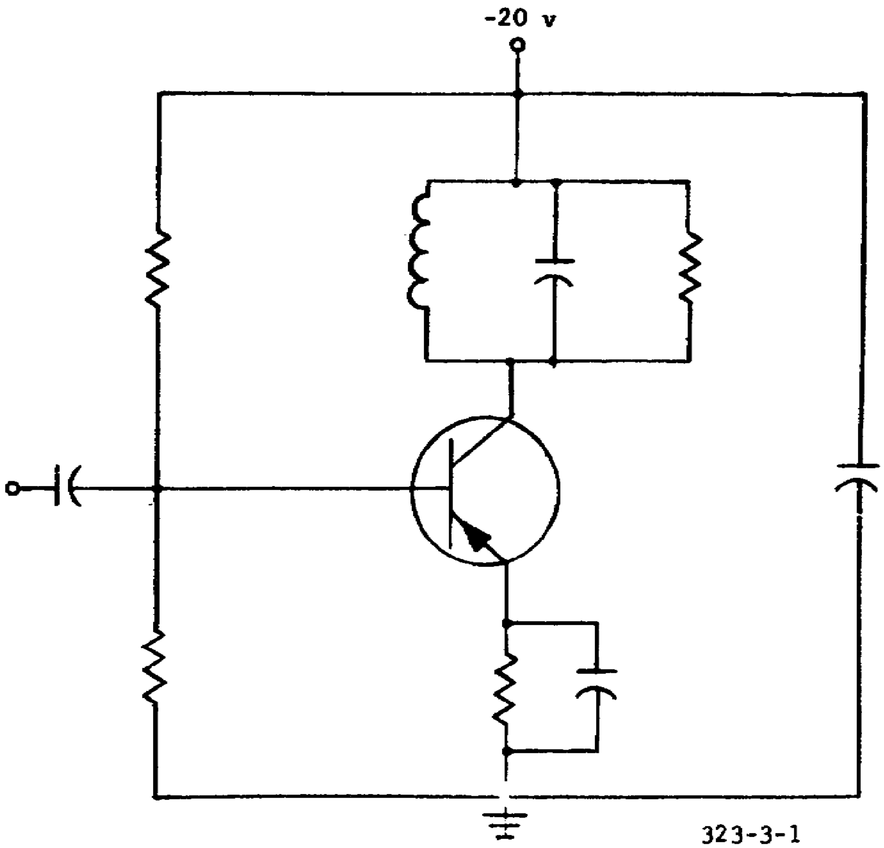

Figure 3-1. Frequency multiplier.

load impedance, P_{OUT} is the power output, N the efficiency, and Vi is the root means square (rms) input voltage. The chart shows that if the frequency ratio (multiplication factor) increases, the power output And efficiency will decrease. You will also note that the input voltage must be increased for each increase in frequency ratio so that a usable output can be obtained. Outputs above the frequency ratio of 5 to 1 are generally not capable of driving the following stage.

c. Limitations. It will be noted that the efficiencies (N) are reasonably close to the expected values (N = 100/n) at the second, third, and fourth harmonics, but become much lower at the higher harmonics. This is probably because of the fact that the minimum collector current pulse duration that could be obtained was 1/8 microsecond, which corresponds to one-half cycle at an output frequency of 4 MHz. At higher output frequencies, this input pulse bridges an excessive portion of the output voltage cycle, and actually extracts energy from the tuned circuit during a portion of the cycle.

3-3. DRIVER AND POWER AMPLIFIER STAGES

Amplifier stages designed primarily to raise the power level of the signal are known as driver and power amplifiers. Driver stages usually develop power

in the order of milliwatts. Power amplifiers develop watts or hundreds of milliwatts of power. This distinction based on power levels is approximate. The power levels of driver and power amplifiers depend on the equipment in which they are used. A driver amplifier, as its name implies, is used to drive a succeeding stage. Thus, the driver stage delivers power to another driver stage or to a power amplifier. Power amplifiers increase the signal power to the necessary level to operate a device such as an antenna.

3-4. SINGLE-ENDED AMPLIFIERS

a. Circuit Arrangements. Circuit arrangements for single-ended driver and power amplifiers do not differ to any marked degree from class A preamplifiers. Drivers and power amplifiers operate at higher collector voltages and currents, however, and are carefully matched for power transfer. Transformer coupling is very useful for matching, and improves efficiency since the dc losses are reduced. Impedance coupling (LC) is sometimes used to obtain a higher efficiency, but it has poor low-frequency response.

b. Efficiency. Efficiency is an important consideration at high power levels, particularly for power amplifiers. As long as we operate class A, efficiency is poor. Both class B and class C operation provide greater efficiency than class A.

3-5. PUSH-PULL AMPLIFIERS

Exact sound reproduction (fidelity) can be realized at higher efficiencies by a push-pull circuit arrangement. Improved efficiency and fidelity can be attained with push-pull amplifiers operating class A. Just as in the case of electron-tube push-pull operation, even-harmonic (nonsymmetrical) distortion is minimized. If the circuit is perfectly symmetrical, such distortion is completely eliminated. Because of this fact, push-pull amplifiers can deliver greater power for an allowable amount of distortion than can two single-ended amplifiers. Moreover, push-pull amplifiers can be operated class B and class AB since even-harmonic distortion can be canceled. Provided there is good circuit symmetry, excellent linearity can be achieved with class AB operation, and fairly good linearity is possible with class B operation.

a. Transformer Type. The class B transformer-coupled amplifier is the simplest type. Note that the NPN transistor circuit shown in figure 3-2 resembles closely the corresponding electron-tube class B push-pull amplifier. Remember that PNP transistors can be used instead, provided the bias polarities are reversed.

(1) Observe in figure 3-2 that there is no forward base-emitter bias; both the base and emitter of Q1 and Q2 are at dc ground potential. Therefore, Q1 and Q2 are cut off; with no-signal input (the static condition) $I_{c1} = 0$ and $I_{c2} = 0$.

(2) A signal applied to the primary of the input transformer produces signals at opposite ends of the center-tapped secondary 180° out of phase, as shown. Therefore, when a negative alternation is applied to the base of Q1, a positive alternation is applied to the base of Q2, and vice versa. Because both Q1 and Q2 have 0 volt base-emitter bias, each will conduct during positive alternations

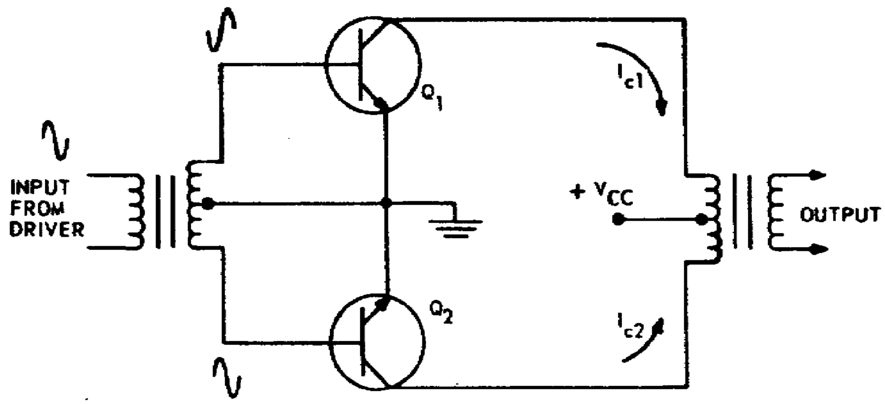

Figure 3-2. Class B push-pull amplifier.

and remain cut off during negative alternations. Since their inputs are 180° out of phase, Q1 is conducting (I_{c1}) while Q2 is cut off, and Q2 is conducting (I_{c2}) while Q1 is cut off. In other words, Q1 and Q2 conduct alternately to supply output current (I_{c1} + I_{c2}) throughout the entire cycle.

(3) This circuit arrangement amounts to having two symmetrically arranged single-ended amplifiers supplying a common load. Sketch A in figure 3-3 is a dynamic curve of a single-ended amplifier; sketch B is the dynamic curve of a push-pull amplifier. Note that the curve in sketch B is merely the combination of the dynamic curves of two single-ended amplifiers. Because of the 180° phase relationship of the input and the circuit arrangement, the positive direction of base currents I_{b1} and I_{b2} are opposite; also, the positive direction of collector currents I_{c1} and I_{c2} are opposite. The input signal wave is projected on the dynamic curve diagram in C of figure 3-3. The output waveshape is a composite of current I_{c1} and I_{c2}. This diagram illustrates clearly the faithfulness of signal reproduction, thus fidelity. Note the distortion that occurs as the signal approaches and passes through zero. This is called crossover distortion and causes odd harmonics of the signal frequency to appear in the output signal.

(4) Crossover distortion can be eliminated by biasing Q1 and Q2 in the forward direction. A simple biasing arrangement is illustrated in figure 3-4. Resistor R is made variable so that we can adjust the bias for class AB operation or class A operation. If properly adjusted for class AB operation, the crossover effect is not evident in the output. A comparison of A in figure 3-5 and B in figure 3-5 shows why this is so. The nonlinearity is effectively canceled and excellent fidelity achieved. If R is adjusted for class A operation, the output waveshape is the resultant of the individual waveshapes as illustrated in C of figure 3-5.

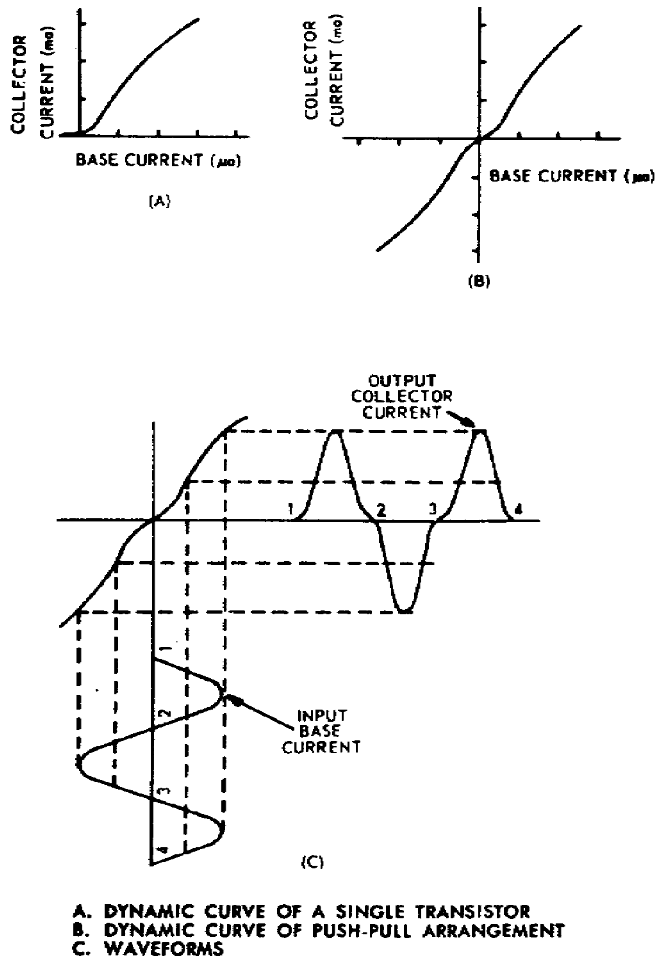

Figure 3-3. Class B push-pull curves.

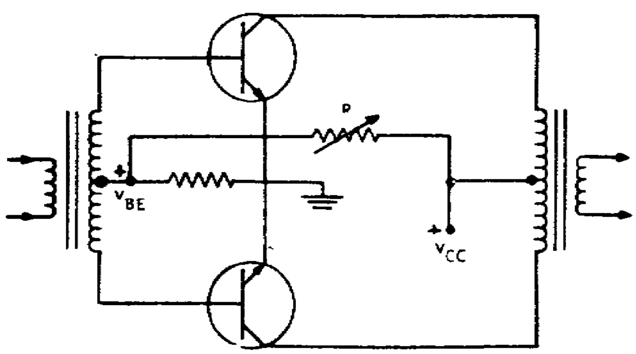

Figure 3-4. Push-pull amplifier that can be biased class AB or A.

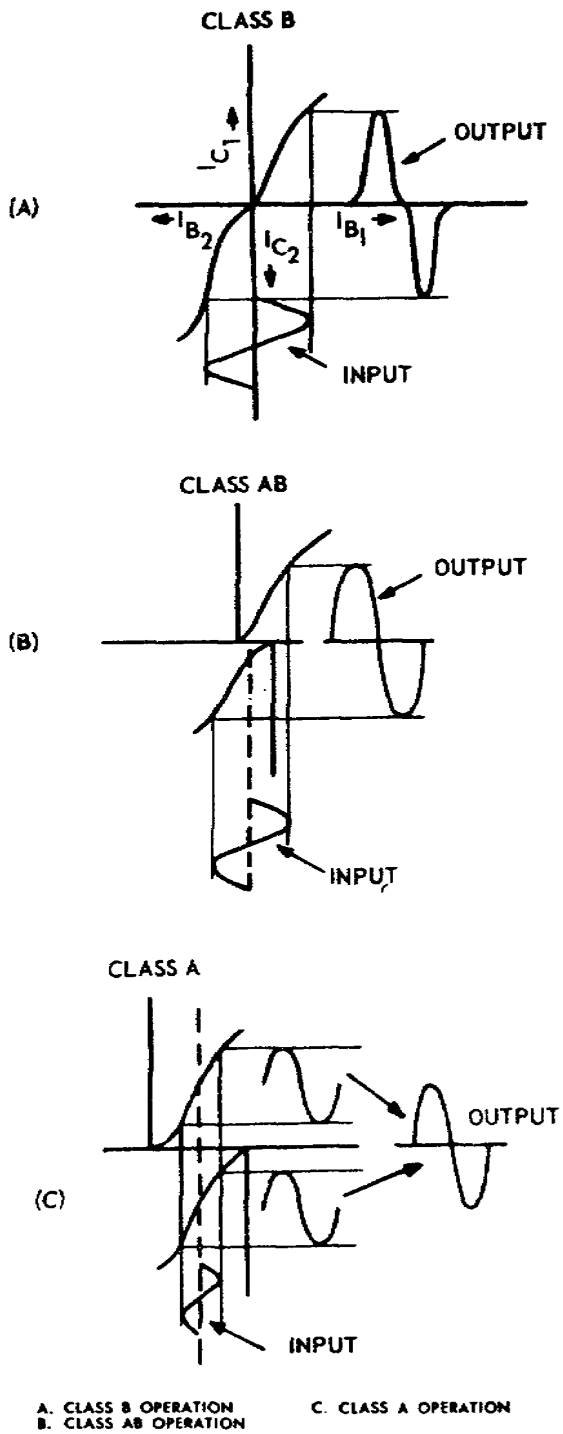

Figure 3-5. Typical output waveforms.

(5) Since class AB operation is more efficient than class A operation, it seems that class AB would always be preferred. The output waveshape looks as good for class AB as it does for class A because we have assumed perfectly matched transistors and symmetrical circuitry. Suppose, however, that the transistors are not perfectly matched or that the circuit is not perfectly symmetrical; the dynamic curves for Q1 and Q2 would no longer be identical. For such a condition, the outputs from a class AB and a class A push-pull amplifier are shown in A of figure 3-6 and B of figure 3-6, respectively. It is quite obvious that the output for class AB operation is distorted. This nonsymmetrical distortion is a result of the presence of even harmonics. Thus, we need to realize that class AB operation requires matched transistors and circuit symmetry if high fidelity is desired. Such requirements somewhat offset the higher efficiency that class AB amplifiers offer.

b. Phase Inverter Driver Amplifier. It is not necessary to use a transformer to obtain input signals of opposite phase for a push-pull amplifier. The circuit in figure 3-7 shows how a driver amplifier can be designed to produce output signals that are 180° out of phase. The values of resistors R1 and R2 are chosen to provide the proper base bias for linear class A operation. Resistors R3 and R4 are practically equal in value so that the signal outputs are the same in amplitude. The normal phase inversion from base to collector occurs across R3, whereas across R4 the signal output is in phase with the input.

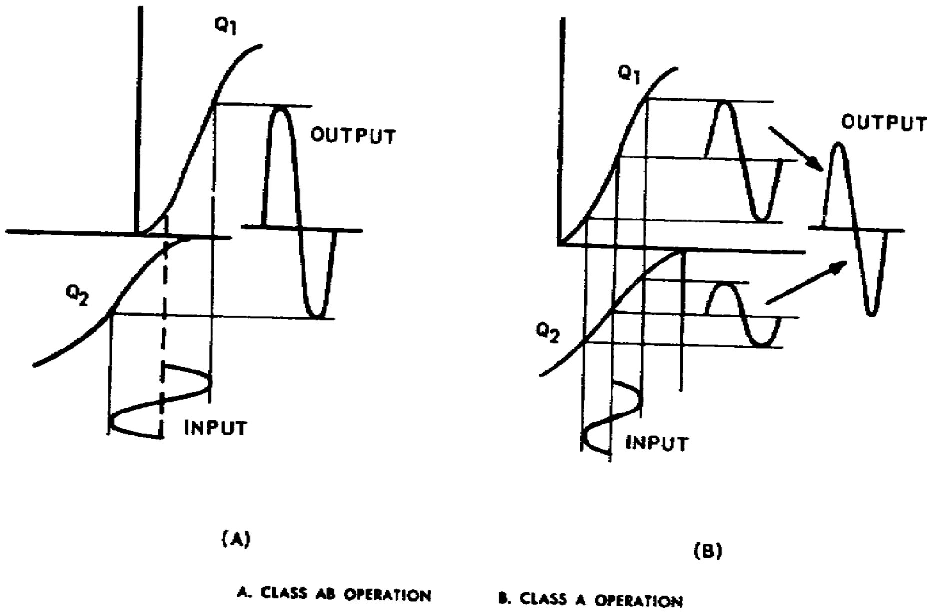

Figure 3-6. Waveforms resulting from nonsymmetrical push-pull circuit.

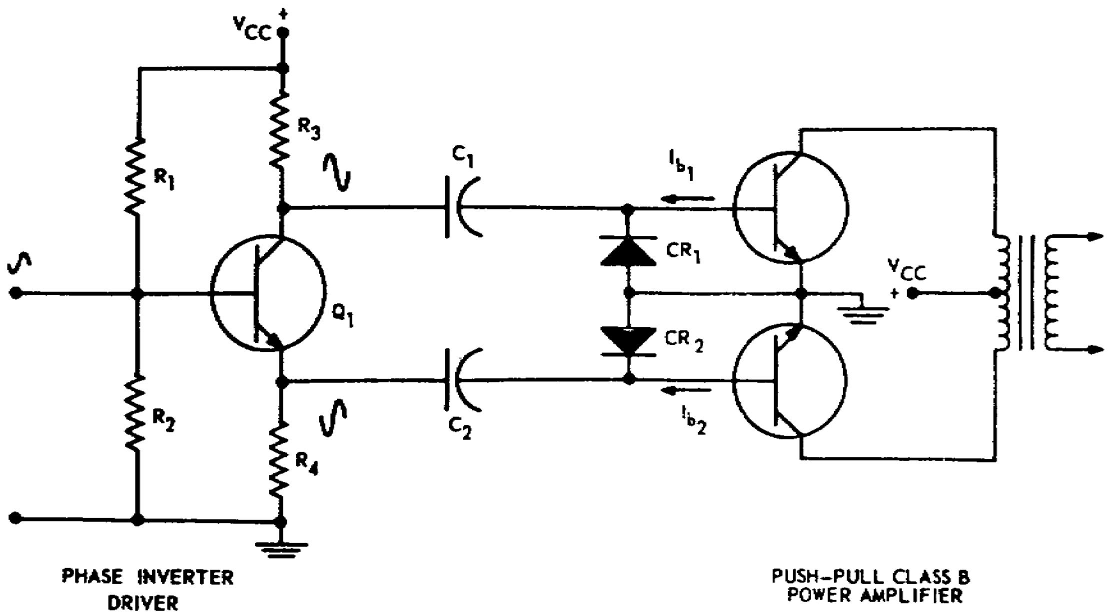

Figure 3-7. Capacitively coupled input to a push-pull amplifier.

(1) Emitter-follower action accounts for the phase of the signal across R4. This action also accounts for the fact that input impedance is desirably higher than ordinary and the output impedance is lower to match the input impedance of the push-pull stage. Another advantage offered is the improved frequency response. Better frequency response can be attributed to two things: degenerative (negative feedback) action and capacitive coupling.

(2) We took care to say capacitive coupling rather than RC coupling, since crystal diodes CR1 and CR2 are used in place of resistors. These are discharge diodes that prevent capacitors C1 and C2 from taking on a charge that would bias the push-pull amplifier well below cutoff. Inasmuch as the transistors draw base current during half a cycle for class B operation, rectified base currents flow into C1 and C2. If CR1 and CR2 were not connected in the circuit as shown, a negative charge would build up to reverse-bias the push-pull transistors. This would correspond to grid-leak biasing of electron tubes. To preclude this unwanted base biasing, CR1 conducts whenever C1 becomes negative with respect to ground, and CR2 conducts whenever C2 becomes negative with respect to ground. Thus, these discharge diodes function to maintain 0 volt base bias.

3-6. COMPLEMENTARY SYMMETRY CIRCUIT

A complementary symmetry circuit arrangement is made possible by the use of an NPN and a PNP transistor. This simple push-pull amplifier circuit shown in figure 3-8, affords the benefits of capacitive coupling, yet does not require a phase inverter nor discharge diodes.

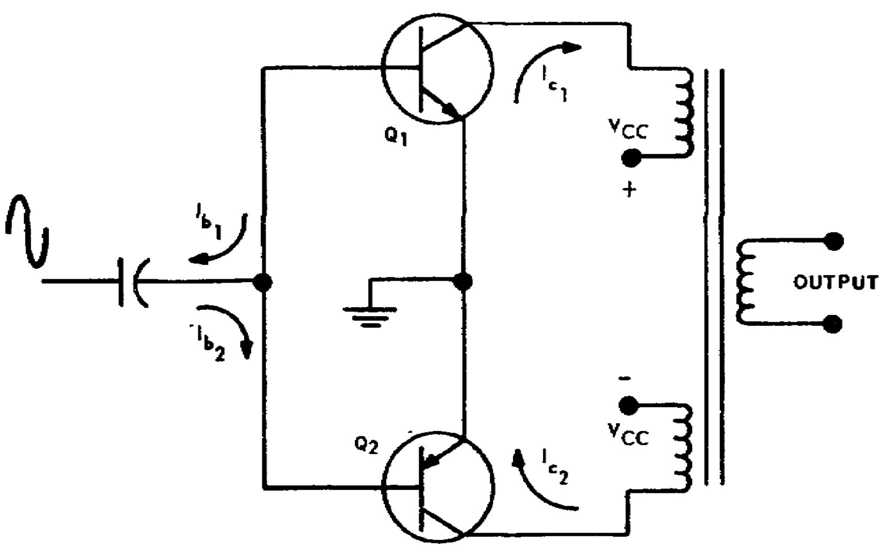

Figure 3-8. Push-pull amplifier using complementary symmetry.

a. Input. Input phase inversion is unnecessary since at zero base bias the NPN transistor (Q1) and PNP transistor (Q2) conduct on alternate half-cycles of the input. When the input signal is positive going, Q1 conducts and Q2 is cut off. When the input signal is negative going, Q2 conducts and Q1 is cut off. Thus, push-pull operation takes place as a result of the complementary action of the transistors.

b. Base Current. Note that I_{b1} and I_{b2} flow in opposite directions. If the transistors are properly matched, these two currents will be equal. Because they are equal and opposite, the resultant charging current flowing into the coupling capacitor is zero. Since no charge will develop to reverse bias the bases, discharge diodes are not needed.

c. Advantage. The basic circuit just discussed illustrates how simplicity and improvement can be attained by using NPN and PNP transistors together. Many varied circuits take advantage of the complementary features of transistors. Such circuits have no electron-tube counterparts.

LESSON EXERCISES

In each of the following exercises, select the ONE answer that BEST completes the statement or answers the question. Indicate your solution by circling the letter opposite the correct answers in the subcourse booklet.

SITUATION

Assume that the FM transmitter shown in figure 2-7 is being modified to increase its efficiency.

Exercises 1 thru 5 are based on this situation.

1. Assume that the crystal in this FM transmitter operates at a frequency of 850 kHz. The center frequency of this transmitter output is

a. 27.2 MHz. c. 81.6 MHz.

b. 54.4 MHz. d. 122.4 MHz.

2. Assume that the transmitter is to be redesigned to have fewer stages and to provide a multiplication of 256. The minimum number of frequency multiplier stages that could be used to obtain this multiplication without excessive loss of output is

a. three.

b. four.

c. five.

d. six.

3. Assume that the unloaded Q of the power amplifier (V9) tank circuit is 180, and the loaded Q is 9. The transfer efficiency of the tank circuit is approximately

a. 75 percent.
b. 85 percent.
c. 95 percent.
d. 100 percent.

4. After changing V5 to a quadrupler to eliminate the first doubler, it is found that parasitic oscillations occur. These parasitics can be suppressed by inserting a

a. parallel-tuned trap in the screen grid lead.

b. series-tuned circuit in the control grid lead.

c. small high-frequency capacitor between pins 3 and 5 of V5.

d. small resistor in the lead between pin 5 of V5 and pin 1 of transformer T1.

5. Analysis of the transmitter circuit shows that the coupling circuit between the fifth frequency doubler and the power amplifier is of the type that is

a. inductive with link coupling.

b. capacitive with a split-stator tuned circuit.

c. capacitive with the control grid at RF ground.

d. inductive with tuned primary and untuned secondary.

6. Assume that a given portable, direct FM transmitter contains a 20.850-MHz oscillator, a frequency doubler, and a power amplifier. If the frequency of the oscillator swings between the limits of 20.848 MHz and 20.852 MHz while being modulated, the frequency deviation of the transmitter is

a. 2 kHz.
b. 4 kHz.
c. 8 kHz.
d. 10 kHz.

7. Analysis of the i_b - e_c curve for a given electron tube shows that the grid cutoff voltage --8 volts, grid voltage at plate saturation = +2 volts. If this tube is to be used as a doubler in an FM transmitter, its operating bias must be adjusted to approximately

a. -20 volts.
b. -8 volts.
c. -4 volts.
d. +2 volts.

8. Assume that the plate power input to the power amplifier of a low-level AM transmitter is 225 watts and the output power is 55 watts. In an FM transmitter which is also low-level modulated the power amplifier with the same power input is capable of producing a maximum power output of

a. 45 to 90 watts.

b. 90 to 135 watts.

c. 135 to 180 watts.

d. 180 to 225 watts.

9. Since class C amplifiers have tuned grid and plate circuits, they often break into oscillation because of the feedback through interelectrode capacitance. In class C amplifiers used in high-frequency FM transmitters, these oscillations are prevented by

a. using tetrode tubes.

b. decreasing the grid excitation.

c. increasing the Q of the tank circuit.

d. inserting an adjustable capacitor between the plate and grid.

10. A comparison of the single-ended amplifier shown in figure 72 of TM 11-668 and the push-pull amplifier shown in A of figure 74 reveals that the input and output capacitances across the tank circuits of the push-pull circuit are one half those in the single-ended circuit. Since the output voltage of the push-pull circuit is twice that of the single-ended circuit, what is the relationship between the two plate load impedances (Z)?

a. Z's of the two circuits are equal.

b. Z of the push-pull circuit is twice that of the single ended.

c. Z of the single-ended circuit is twice that of the push-pull.

d. Z of the push-pull circuit is four times that of the single ended.

11. A circuit that permits a triode to be operated as a power amplifier at high frequencies without neutralization may be described as having

a. grid-cathode input, plate-cathode output, and grounded cathode.

b. grid-ground input, cathode-ground output, and grounded plate.

c. cathode-ground input, plate-ground output, and grounded grid.

d. grid-cathode input, plate-ground input, and grounded grid.

12. The grid-tank circuit that would be most appropriate for use in a power amplifier located several feet from the driver is shown in TM 11-668, figure 75, sketch

a. C.

b. D.

c. E.

d. G.

13. Assume that the power amplifier in an FM transmitter is driven by a 16-watt signal. The grid draws a current of 18 ma, and the grid bias is -75 volts. For optimum operation, the values of the grid-tank circuit components should be chosen to present an impedance that is

a. less than 10K.

b. between 10K and 100K.

c. between 100K and 1 megohm.

d. greater than 1 megohm.

14. Cross-neutralization of a push-pull amplifier causes an increase in the output capacitance which, in turn, limits the operating frequency. Assume that the push-pull amplifier shown in A of figure 74, TM 11-668, has the values grid-cathode capacitance -6.5 pf, plate-cathode capacitance = 5.5 pf, grid-plate capacitance = 14.5 pf. The INCREASE in output capacitance caused by the neutralizing capacitors is

a. less than 10 pf.

b. between 10 pf and 15 pf.

c. between 15 pf and 20 pf.

d. greater than 20 pf.

15. Sketch A in figure 77 of TM 11-668 shows an ideally tuned power amplifier. Assume that the unloaded Q_O of the tank circuit (L1 -C1) is 200, the operating Q (Q_L) is 10, and the value of X_{L1} is 1,500 ohms. The impedance presented to tie amplifier under load is

a. less than 1K.

b. between 1K and 10K.

c. between 10K and 20K.

d. greater than 20K.

16. Transistors used in multiplier stages should have a good high-frequency response, a high collector dissipation rating, and a high

a. input voltage.

b. input resistance.

c. collector voltage.

d. emitter-to-base bias.

17. Assume that a frequency of 2.5 MHz is applied to a transistorized multiplier stage. If the output of the stage is 10 MHz, what is the approximate efficiency of the circuit?

a. 4 percent

b. 25 percent

c. 50 percent

d. 67 percent

18. Whenever the multiplication factor of the circuit shown in figure 3-1 is changed, several output characteristics also change. A change that is noticed when the multiplication factor is increased is:

a. increase in output efficiency.

b. increase in output power.

c. decrease in output power.

d. decrease in output voltage.

19. The purpose of the discharge diodes in the push-pull amplifier shown in figure 3-7 is to

a. establish a small reverse bias for each transistor.

b. discharge any positive base potential.

c. maintain base bias at 0 volt.

d. rectify the base current.

20. How can you arrange transistor amplifiers to obtain push-pull operation without using a phase inversion stage?

a. Connect two PNP transistors in parallel.

b. Connect two NPN transistors in series.

c. Connect two NPN transistors in a complementary symmetrical arrangement.

d. Connect NPN and PNP transistors in a complementary symmetrical arrangement.

CHECK YOUR ANSWERS WITH LESSON 3 SOLUTION SHEET PAGE 52, 53 and 54.

LESSON 4

FM TRANSMITTERS

SCOPE....................................Operation of divider and automatic frequency control circuits (AFC); analysis of comparator circuits, to include the double-tuned, phase, and pulse discriminators; circuit analysis of complete FM transmitter.

CREDIT HOURS.............................2

TEXT ASSIGNMENT..........................TM 11-668, para 42-51; Attached Memorandum, para 4-1 thru 4-5

MATERIALS REQUIRED.......................None

SUGGESTIONS..............................Read the assignment in TM 11-668 and review paragraphs 39-41 before you read the attached memorandum.

LESSON OBJECTIVES

When you have completed this lesson, you will be able to:

1. Analyze the operation of the different types of AFC circuits.

2. State the purpose and explain the operation of frequency-divider circuits.

3. Locate stages in an FM transmitter that perform specified functions.

4. Identify the frequencies and signals that appear at various points in an FM transmitter.

ATTACHED MEMORANDUM

Section I. FREQUENCY DIVIDERS

4-1. SYNCHRONOUS DIVIDER

The frequency dividers of the type under consideration in this section produce a sinusoidal voltage or current at a submultiple of the sinusoidal input frequency. As indicated in the text, waveform devices such as multivibrators or counters can be used, with filtering, to produce a sinusoidal output. However, some nonlinearity must be present to effect division. As a practical matter, a synchronous oscillator is usually involved in the

generation of subharmonics. In one method, a frequency is injected into an oscillator operating at a frequency other than the one injected. It is assumed that a frequency is generated within the oscillator so that a beat frequency can be produced between the two frequencies. Such a simple system is usually termed a locked oscillator and is frequently useful when the frequency ratio (input) is small. A more complicated system can be devised in which the functions of frequency multiplication, beating or phase comparison, and oscillator phase control or locking are carried out in separate portions of the circuit. Although such a device is capable of good performance at large frequency ratios, it is complicated, and will not be considered here.

4-2. LOCKED-OSCILLATOR FREQUENCY DIVIDER

a. Circuit Description. The simple locked-oscillator frequency divider, shown in figure 4-1, is capable of providing reliable frequency division at small frequency ratios. It consists of a grounded base oscillator, with the synchronizing voltage applied between base and ground. Successful operation of this oscillator as a frequency divider requires that harmonics be produced at frequencies near the input frequency. The circuit employs dc stabilization to assure reliable starting.

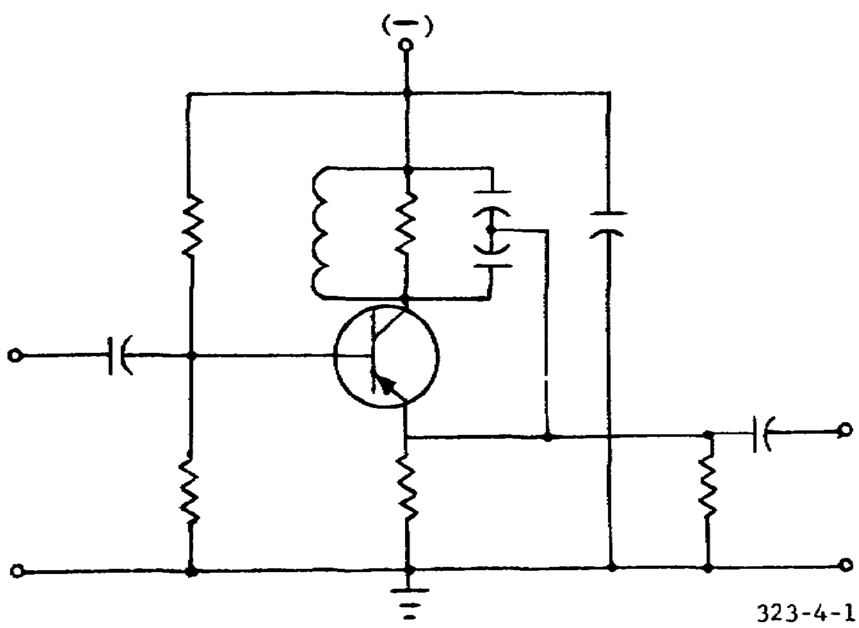

Figure 4-1. Locked-oscillator frequency divider.

b. Operation. The oscillator operates at a frequency that is determined by its frequency-determining network located in the collector circuit. When an input frequency is applied to the base, the oscillator's resonant frequency is altered slightly. In effect, the input frequency locks the oscillator's

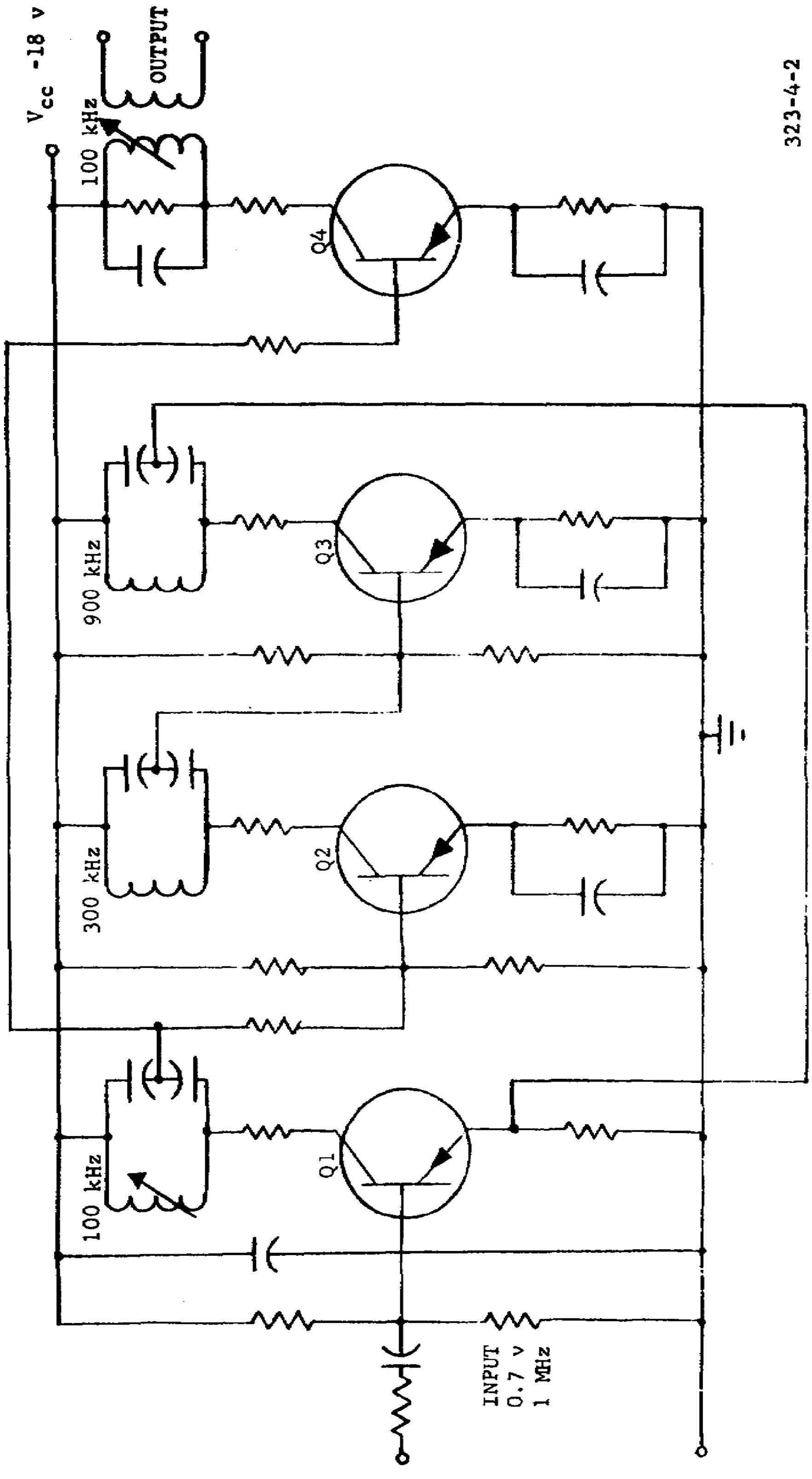

Figure 4-2. Regenerative frequency divider.

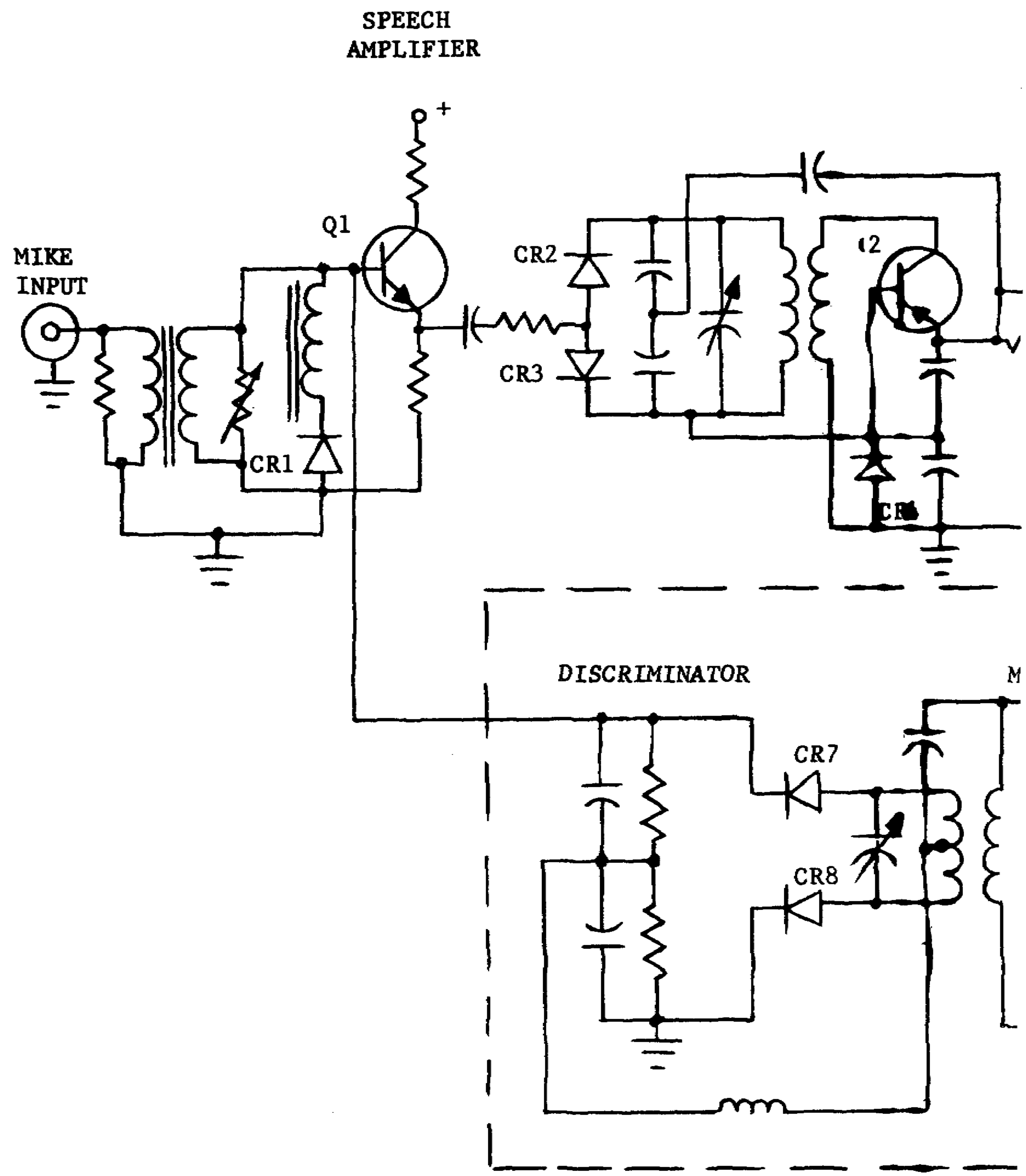

Figure 4-3. Transistorized transmitter.

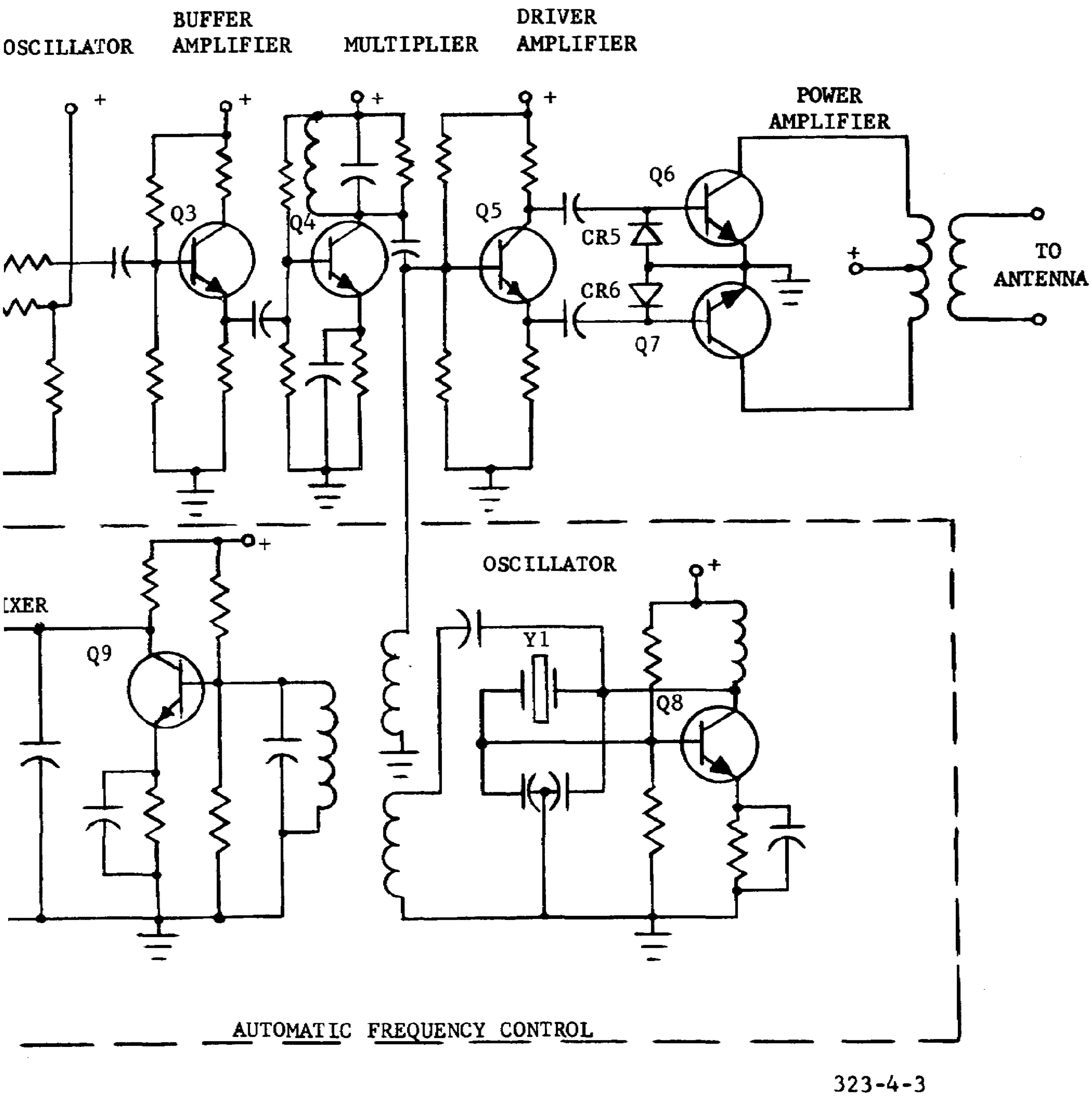

Figure 4-3. Transistorized transmitter. (cont)

frequency at a submultiple of the input frequency. The output frequency is slightly greater than the resonant frequency of the oscillator's tuned circuit.

4-3. REGENERATIVE FREQUENCY-DIVIDER CIRCUIT

a. General. The divider shown in figure 4-2 is driven at a frequency of 1 MHz and produces an output frequency of 100 kHz. The circuit is stable and reliable and, if properly adjusted, will not oscillate in the absence of an input. The phase stability is good and the operating bandwidth is such that excessively close tolerances in the tuned circuit need not be maintained.

b. Circuit Operation. Transistor Q1 is a mixer that receives an input of 0.7 volt rms at an input frequency of 1 MHz from an external source. The output of the mixer is at 100 kHz. The output is processed through two tripler stages to produce an output of 900 kHz. This signal drives the emitter of Q1 to produce a frequency difference of 100 kHz, which is selected by means of a tapped tuned circuit. The resistor connected in series with the collector of the transistor is used to suppress a form of negative resistance oscillation that is encountered with high-frequency junction transistors when bottoming occurs. It also serves the very useful function of limiting the peak collector current to a satisfactory value. Tripler stage Q2 is driven from a capacitive tap on the 100-kHz tuned circuit through a series-isolating resistor which also helps to prevent very high frequency parasitics. The second tripler, Q3, produces the 900-kHz frequency required for the mixer. The output amplifier, Q4, is driven by the mixer output, and has sufficient gain to deliver 20 milliwatts to a 50-ohm load. The resistor, across the tuned circuit of Q4, stabilizes the amplifier and also prevents an excessively high voltage from being developed at this point in absence of a load. The frequency multiplier stages and the output amplifier also contain series-collector resistors for the reasons given above.

c. Alignment. The alignment of the divider is best accomplished by driving the base of each transistor separately at the frequency of the collector tuned circuit. The tuned circuit is then adjusted for maximum response while the input is decreased, if necessary, to avoid limiting. An input of 0.7 volt rms at 1 MHz should then be applied to Q1; the system should oscillate and, as a final step, each tuned circuit should be adjusted to the center of the range over which correct operation is desired. When properly adjusted, the divider should work as the supply is varied from 5 to 40 volts. Increasing the voltage beyond 40 may cause transistor damage, and should not be attempted. The output should be zero in the absence of an input, except for a small amount of noise. The operating bandwidth should be at least ±2 percent at the middle of the supply voltage range.

Section II. TRANSMITTER

4-4. GENERAL

The transmitter illustrated in figure 4-3 is a simplified transistorized version of the one illustrated in figure 100 of TM 11-668. The transmitter comprises circuits that were studied in previous lessons, with the exception of the AFC circuit.

4-5. AFC

The-AFC circuit is used to control the center frequency of oscillator Q2. The circuit compensates for any variations that might be caused by temperature changes, humidity, or vibrations. The circuit contains a crystal oscillator stage, a mixer stage, and a discriminator stage.

a. Crystal Oscillator. Transistor Q8 and its associated components make up a crystal-controlled Colpitts oscillator. The inductance required to resonate with the tapped capacitors is provided by crystal Y1.

b. Mixer. Mixer stage Q9 heterodynes the two signals and produces an out put that is analyzed in the discriminator stage.

c. Discriminator. This phase discriminator produces a dc output voltage that is proportional to the frequency error of the input signal. The polarity of the dc signal depends on whether the input signal is higher or lower than the desired frequency. The dc output voltage is applied to the speech amplifier to control the frequency of oscillator stage Q2.

LESSON EXERCISES

In each of the following exercises, select the ONE answer that BEST completes the statement or answers the question. Indicate your solution by circling the letter opposite the correct answers in the subcourse booklet.

1. Figure 82 of TM 11-668 is a functional block diagram of an FM transmitter and shows an oscillator corrector as part of the AFC system. The electron tube in figure 100 of TM 11-668 that functions as this corrector is

a. V2.

b. V3.

c. V4.

d. V5.

2. To obtain a zero potential between point A and ground in the circuit shown in figure 84 of TM 11-668, the frequency of the signal in T1 must be equal to the

a. resonant frequency of T2.

b. resonant frequency of T3.

c. difference between the resonant frequencies of T2 and T3.

d. sum of the resonant frequencies of T2 and T3 divided by 2.

3. An electron tube with a single cathode can be used in the double-tuned discriminator shown in figure 84 of TM 11-668. However, the same tube CANNOT be used in the phase discriminator shown in figure 87 because

a. the emission is too low.

b. the circuit becomes unstable.

c. a potential must exist between the two cathodes.

d. high-frequency interference distorts the output.

4. Assume that an AFC system similar to that shown in figure 82 of TM 11-668 uses the basic phase discriminator shown in figure 87 in place of the mixer and discriminator. A positive output voltage of the discriminator indicates that the multiplied input frequency from the master oscillator is

a. equal to the crystal oscillator frequency.

b. less than the crystal oscillator frequency.

c. greater than the crystal oscillator frequency.

d. In phase with that of the crystal oscillator.

5. In the AFC system shown in figure 93 of TM 11-668, a multivibrator is used in the block labeled

a. PHASE SHIFTER.

b. FIRST DIVIDER.

c. MASTER OSCILLATOR.

d. BALANCED MODULATOR.

6. Assume that a signal with a frequency of 440 kHz is to be divided by 4. The oscillator that is to be synchronized by this voltage must have a free-running frequency of

a. less than 110 kHz.

b. between 110 kHz and 220 kHz.

c. between 221 kHz and 440 kHz.

d. greater than 440 kHz.

7. The stages in the AFC system in figure 100 of TM 11-668 include a

a. driver, mixer, and double-tuned discriminator.

b. crystal oscillator, mixer, and phase discriminator.

c. multivibrator, frequency divider, and pulse discriminator.

d. harmonic generator, discriminator, and reactance modulator.

8. Compared with a double-tuned phase discriminator, the advantages of a pulse discriminator include

a. more accurate timing, no frequency-divider circuits, and no stabilizing circuits to tune.

b. no frequency-divider circuits, no stabilizing circuits to tune, and no limiter stages.

c. no stabilizing circuits to tune, no limiter stages, and fewer components.

d. no limiter stages, fewer components, and more accurate timing.

9. Assume that an FM transmitter is equipped with a motor-control AFC system. If the master oscillator drifts to a frequency above the center frequency, the AFC system corrects the situation by

a. modulating the oscillator with a stable frequency.

b. changing the capacitance across the master oscillator tank circuit.

c. injecting an increased amount of inductive reactance across the master oscillator.

d. applying two out-of-place low-frequency signals to the master oscillator.

10. Compared with an indirect FM transmitter, an advantage of a direct FM transmitter is that it generally

a. requires fewer frequency multiplier stages.

b. produces a lower frequency deviation at the oscillator.

c. operates without automatic frequency control.

d. produces a more stable output frequency.

11. An RF amplifier with tuned circuits in the grid and plate will tend to oscillate if the grid circuit receives positive feedback from the plate circuit. The driver stage (V8) of the FM transmitter shown in figure 99 of TM 11-668 is kept from oscillating by the

a. negative feedback voltage that is coupled through C18.

b. transformer coupling between the grid and plate-tank circuits.

c. degenerative feedback voltage developed by C18 and coupled to the input circuit by C17.

d. shield formed between the input and output circuits when the stage is operated in the grounded-grid arrangement.

12. The reason for grounding the center of L7 for RF in figure 100 of TM 11-668 and removing the outputs from the top and bottom of L7 is that it provides a means for developing the

a. bias voltage needed for V11 and V12.

b. out-of-phase input voltages needed for V11 and V12.

c. frequency sample needed for comparison in the AFC circuit.

d. degenerative feedback needed to prevent oscillations in V10.

13. The block diagram in figure 82 of TM 11-668 shows the basic appearance of all AFC circuits. One type of circuit that can be used in the block labeled OSCILLATOR CORRECTOR is the

a. comparator.

b. multiplier.

c. balanced modulator.

d. reactance-tube modulator.

14. Motor-control AFC systems used in FM transmitters require the use of frequency dividers. A typical frequency-divider circuit that uses a two-stage resistance-capacitance-coupled amplifier with the output of the second stage fed back to the input of the first stage is called a

a. synchronized multivibrator.

b. synchronized oscillator.

c. regenerative modulator.

d. trigger circuit.

15. The circuit diagram of an indirect FM transmitter is shown in figure 99 of TM 11-668. The electron tube that is used as a grounded-grid amplifier stage is

a. V3.

b. V4.

c. V7.

d. V9.

16. Basically, there are three frequencies present in the circuit shown in figure 4-1--the input, the output, and the resonant frequencies. What is the relationship between these frequencies?

a. The input frequency is greater than the output frequency but is less than the resonant frequency.

b. The input frequency is less than the output frequency but is greater than the resonant frequency.

c. The input frequency is greater than both the resonant and output frequencies.

d. The input frequency is less than both the resonant and output frequencies.

17. One of the purposes for using the resistors in the collector circuits of Q2 and Q3 in the divider circuit shown in figure 4-2 is to

a. multiply the incoming frequency by 3.

b. heterodyne the input and feedback signals.

c. suppress negative resistance oscillations in the transistors.

d. limit the input frequencies to one third of their original values.

18. Since the output of the divider shown in figure 4-2 is 100 kHz, what is the reason for developing the 900-kHz frequency?

a. To bias mixer stage Q1

b. To lock transistor Q4 at 100 kHz

c. To establish a reference frequency for divider Q2

d. To heterodyne with the input for the development of the 100-kHz output

19. Although the discriminator used in figure 4-3 employs semiconductor diodes, it functions exactly the same as the electron-tube type that is called a

a. balanced modulator discriminator.

b. double-tuned discriminator.

c. pulse discriminator.

d. phase discriminator.

20. If a small dc voltage is applied to the base of Q1 in figure 4-3, either a frequency error or a defective component exists in the transmitter. The frequency error that probably exists is the one generated by

a. oscillator Q2.

b. oscillator QS.

c. audio stage Q1.

d. driver Q5.

CHECK YOUR ANSWERS WITH LESSON 4 SOLUTION SHEET PAGES 54 and 55.

HOLD ALL TEXTS AND MATERIALS FOR USE WITH EXAMINATION AND SIG 324.

LESSON SOLUTIONS

SIGNAL SUBCOURSE 323......................FM Radio Transmitters

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LESSON 1.................................Principles of FM

All references are to TM 11-668, unless otherwise indicated.

1. a--para 2, 3

The peak amplitude is the maximum voltage in either the positive or negative direction. Hence, 5 volts.

Figure 1-1 shows 8 cycles in 0.0001 second. Therefore, the number of cycles occurring in one second is 8 x 10,000 = 80,000. The frequency is 80,000 Hz, or 80 kHz

2. a--para 3a

3. b--para 3b(1)

For 100-percent modulation, the modulating voltage must equal the carrier voltage. Therefore, the minimum carrier voltage is 30 volts.

4. b--para 3c(2)

5. b--para 4d(4)

$$\Delta F = \Delta \phi \; f \cos (2\pi ft)$$

$$= \frac{\pi}{6} \times 1{,}200 \times (\pm 1)$$

$$= \pm 628 \text{ Hz}$$

Hence, the carrier varies between the values of 99,372 Hz and 100,628 Hz.

6. a--para 5

7. c--para 7

8. d--para 10c

$$\text{Modulation index (MI)} = \frac{\text{maximum frequency deviation}}{\text{maximum frequency of modulating signal}}$$

$$= \frac{40 \text{ kHz}}{5 \text{ kHz}}$$

$$= 8$$

9. b--para 10c

$$\text{Modulation index} = \frac{\text{maximum frequency deviation}}{\text{maximum frequency of modulating signal}}$$

$$\text{Maximum frequency of modulating signal} = \frac{\text{maximum frequency deviation}}{\text{modulation index}}$$

$$= \frac{40 \text{ kHz}}{5} = 8 \text{ kHz}$$

10. b--para 10d

A deviation of 40 kHz represents 100-percent modulation; therefore, an 80-percent modulation will cause a 32-kHz (40 kHz x 80% = 32 kHz) deviation.

11. b--para 11h, i; Attached Memorandum, para 1-1

Channel width = 92.2 MHz - 92.1 MHz = 0.1 MHz, or 100 kHz

Guard band = 2 x 10 kHz = 20 kHz

Frequency swing = 100 kHz - 20 kHz = 80 kHz

$$\text{Frequency deviation} = \frac{\text{frequency swing}}{2} \approx \frac{80 \text{ kHz}}{2} = 40 \text{ kHz}$$

12. c--para 11h(2), table I

Effective bandwidth (MI = 5) = 16 f_A = 16 x 10 kHz = 160 kHz

Effective bandwidth (MI = 15) = 38 f_A = 38 x 10 kHz = 380 kHz

13. c--para 11b(2), table I

fs-fc = 97.475 MHz - 97.400 MHz

= 0.075 MHz, or 75 kHz

Effective bandwidth = 2 x 75 kHz = 150 kHz = 50 f_A

Table I shows that an effective bandwidth of 50 f_A results from the production of 25 sidebands with an MI of 20.

14. c--para 12d(6), (7)

$$\text{Modulation index} = \frac{\text{deviation}}{\text{pulse repetition rate}} = \frac{3 \text{ kHz}}{1 \text{ kHz}} = 3.0$$

15. d--para 12d(5), fig. 25, 29

Since the transmitter is pulse-frequency modulated at the same MI of 5, the increase in bandwidth is approximately 400 percent (fig. 29). Hence, the increase in effective bandwidth equals the peak-to-peak deviation times 400 percent (7.5 kHz x 2 x 400% = 60 kHz).

The effective, or total, bandwidth becomes (7.5 kHz x 2) + 60 kHz = 75 kHz.

16. a--para 13d

Time constant = R x C

$$C = \text{Time constant}/R$$

$$C = 75 \times 10^{-6}/50{,}000 = 0.0015 \times 10^{-6}$$

$$C = 0.0015 \text{ microfarad}$$

17. c--para 13c (4), fig. 31

From figure 31 it is seen that a rise from 3 kHz to 15 kHz gives an increase in response of 12 decibels (db)(17 db - 5 db - 12 db). A 12-db increase is equivalent to doubling the voltage twice, or increasing voltage amplitude by 4 to 16 volts.

18. c--para 13c

$$\text{Time constant} = \frac{L}{R} = \frac{6.8 \text{ h}}{68{,}000 \text{ ohms}}$$

$$= 0.000100 \text{ second, or } 100 \text{ microseconds}$$

19. a--para 15c

20. c--para 15c

There will be no appreciable interference if the desired signal is twice as large as the interfering signal.

LESSON 2................................Methods of Producing FM

All references are to TM 11-668, unless otherwise indicated.

1. b--para 18, 19

$$f = \frac{1}{6.28\sqrt{LC}} = \frac{1}{\sqrt{6.28 \quad 0.9 \times 10^{-6} \times 0.004 \times 10^{-6}}}$$

$$= \frac{1}{6.28\sqrt{0.0036 \times 10^{-12}}} = \frac{1}{6.28 \times 0.06 \times 10^{-6}}$$

$$= 2.65 \text{ MHz.}$$

Frequency deviation - 3.75 MHz - 2.65 MHz - 1.10 MHz.

2. b--para 18, 20

At 3 MHz, $X_L - 2\pi fL - 6.28 \quad \times (3 \times 10^6) \times (30 \times 10^{-6}) - 565$ ohms.

Since $X_L = X_C$ in a resonant circuit, and the capacitance is unchanged

at 2.5 MHz, $X_L = X_C = \frac{1}{2\pi fC} = \frac{1}{6.28 \times 2.5 \times 10^6 \times 94 \times 10^{-12}} = 678$ **ohms.**

The required increase in inductance reactance is 678 ohms - 565 ohms = 113 ohms, or approximately 110 ohms.

3. b--para 21d

Amplification factor $(\mu) = gm \times r_p$

$= 5{,}000 \times 10^{-6} \times 0.7 \times 10^6$

$= 3{,}500$

4. c--para 22b(3)(as changed), 22e(2)

$$Zab = \frac{1}{gm}\left(1 + \frac{Za}{Zb}\right)$$

$$Zab = \frac{1}{5{,}000 \times 10^{-6}}\left(1 + \frac{R1}{X_{C1}}\right)$$

$$X_{C1} = \frac{1}{2\pi fC1} = \frac{1}{6.28 \times 22.6 \times 10^6 \times 50 \times 10^{-12}} = 141 \text{ ohms}$$

$$Zab = 200\left(1 + \frac{100{,}000}{141}\right)$$

$$Zab = 200\ (1 + 709) = 142{,}000 \text{ ohms, or } 142K$$

5. d--para 22e(2)

$$Li = \frac{R_L\ C_L}{gm} = \frac{100 \times 10^3 \times 50 \times 10^{-12}}{5{,}000 \times 10^{-6}} = 1 \text{ mh}$$

6. d--pare 22e(5)

7. d--para 22d(2)

The arrangement of the plate-load components in figure 38 causes a capacitive reactance to be injected. The Injected capacitance is:

Ci - gm x R x C

Ci - 7,000 x 10-6 x 1,000 x 50 x 10^{-12}

Ci - 350 pf

8. b--para 22e(4)

$$Li = \frac{L_L}{gm\ R_L}$$

$$7.6 \times 10^{-6} = \frac{0.4 \times 10^{-3}}{gm \times 15 \times 10^3}$$

$$gm = \frac{0.4 \times 10^{-3}}{15 \times 10^3 \times 7.6 \times 10^{-6}} = \frac{0.4}{114}$$

gm = 0.0035 mhos, or 3,500 micromhos

9. c--para 26

The total phase shift is 180° at the oscillating frequency. Hence, when the increased variable resistance reduces the phase shift for one section, the remaining sections increase their phase shift when the frequency adjusts to a lower value.

10. a--para 30

11. b--para 31f, 32c, 33c, 34a

12. d--para 34g

13. a--para 35d, fig. 57, 58

From A of figure 58, TM 11-668, the amplitude of this AM component is equal to vector AD minus vector AB.

$$AD - AB = \sqrt{10^2 + 6^2} - 10$$
$$= \sqrt{136} - 10$$
$$= 11.7 - 10$$
$$= 1.7 \text{ volts}$$

14. b--Attached Memorandum, para 2-1<u>b</u>

15. a--Attached Memorandum, para 2-4<u>b</u>(2)

16. d--Attached Memorandum, para 2-2

17. d--Attached Memorandum, para 2-4<u>b</u>(1)

18. c--Attached Memorandum, para 2-3<u>b</u>

19. b--Attached Memorandum, para 2-4<u>b</u>(1)

20. c--para 31; fig. 51

LESSON 3..................................FM Transmitter Circuits

All references are to TM 11-668, unless otherwise indicated.

1. c--para 40<u>c</u>(5)

$$\text{Output frequency} = 2 \times 3 \times 2 \times 2 \times 2 \times 2 \times \text{crystal frequency}$$
$$= 96 \times 850 \text{ kHz}$$
$$= 81.6 \text{ MHz}$$

2. b--para 40<u>c</u>(5), (6)

The maximum multiplication by a single stage is five, but five is ruled out because it is not a proper factor of 256. The multiplication factor of 256 can be attained by using four quadrupler stages (4 x 4 x 4 x 4 = 256).

3. c--para 41<u>h</u>(4)

$$\textbf{Transfer efficiency} = \frac{Q_O - Q_L}{Q_O} \times 100$$
$$= \frac{180 - 9}{180} \times 100 = \frac{17,100}{180} = 95 \text{ percent}$$

4. d--para 41<u>k</u>(4)

5. d--para 41<u>g</u>

6. b--para 40<u>b</u>

Upper frequency limit = 2 x 20.852 MHz - 41.704 MHz

Center frequency = 2 x 20.850 MHz = 41.700 MHz

Frequency deviation = 41.704 MHz = 41.700 MHz

= 0.004 MHz, or 4 kHz

7. a--para 40<u>c</u>(2), (3), (4)

8. c--para 41<u>b</u>(4)

The power amplifier of a low-level AM transmitter must provide linear amplification which in this case is about 25 percent efficient $\left(\frac{\text{55-watt output}}{\text{225-watt input}}\right)$, whereas the power amplifier of an FM transmitter may be operated at the more efficient class C. Since the plate efficiency of a class C amplifier is from 60 percent to 80 percent,

Power out_1 = 0.60 x 225 watts - 135 watts

Power out_2 - 0.80 x 225 watts = 180 watts

9. a--para 41<u>d</u>

10. d--para 41<u>f</u>(3)

11. c--para 41<u>e</u>

12. d--para 41<u>g</u>(10)

13. b--para 41<u>g</u>(2)

$$\text{Grid-tank circuit impedance} = \frac{\text{driving power}}{(i_g)^2}$$

$$= \frac{16 \text{ watts}}{(0.018)^2}$$

$$= \frac{16}{0.000324}$$

$$= 50\text{K}$$

14. d--para 41<u>f</u>(1), (2)

The output capacitance of an unneutralized push-pull amplifier is one-half the output capacitance of one tube. The output capacitance of a neutralized push-pull amplifier is one-half the output capacitance of one tube plus twice the grid-plate capacitance. Hence,

increase in capacitance = 2 x (grid-plate capacitance)

= 2 (14.5 pf)

= 29 pf.

15. c--para 41h(4)

Load impedance $= Q_L \times X_{L1}$

$= 10 \times 1{,}500$

= 15,000 ohms, or 15K

16. c--Attached Memorandum, para 3-2a

17. b--Attached Memorandum, para 3-2c

To produce an output of 10 MHz with a 2.5-MHz input, the collector circuit must be tuned to the fourth harmonic $(\frac{10 \text{ MHz}}{2.5 \text{ MHz}} = 4)$. Therefore, the approximate efficiency $N = \frac{100}{n} = \frac{100}{4} = 25$ **percent**

18. c--Attached Memorandum, para 3-2

19. c--Attached Memorandum, para 3-5b(2)

20. d--Attached Memorandum, para 3-6a

LESSON 4.................................FM Transmitters

All references are to TM 11-668, unless otherwise indicated.

1. a--para 42b

2. d--para 43b

3. c--para 43d(1)

Using a single cathode would short the output load circuit. When the frequency varies from the center frequency in a discriminator, a potential difference must appear between the two cathodes to obtain an output voltage that is proportional to the frequency change.

4. c--para 43d(2)

5. b--para 45b(1)

6. a--para 45c

The output is 1/4 x 440 kHz, or 110 kHz. However, the free-running frequency must be less than the output for greatest stability.

7. b--para 47g

8. a--para 43f(2), (11), (12)

9. b--para 44c

10. a--para 47a

11. d--para 41e, 46g, h

12. b--para 47h

13. d--para 43c(1)

14. a--para 45b(1)

15. d--para 46g

16. c--Attached Memorandum, para 4-2b

17. c--Attached Memorandum, para 4-3b

18. d--Attached Memorandum, para 4-3b

19. d--para 43d, 47g; Attached Memorandum, para 4-5c

20. a--Attached Memorandum, para 4-5